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OF

VOLUME I. (SERIES II.)

[NOVEMBER, 1877.]

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VOLUME I. (NEW SERIES).

MEMOIR No. 1.

ON GREAT TELESCOPES OF THE FUTURE.

BY

HOWARD GRUBB, F.R.A.S.,

HONORARY MASTER IN ENGINEERING, UNIVERSITY OF DUBLIN.

[READ BEFORE THE SOCIETY, FEBRUARY 19TH, 1877.]

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ON GREAT TELESCOPES OF THE FUTURE.

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HOWARD GRUBB, F.R.A.S., Honorary Master in Engineering, University of Dublin.

I propose in the present communication to consider the relative advantages and disadvantages of the Refracting and Reflecting Telescope, in what manner those advantages and disadvantages are likely to be modified by any great advance in size over those at present in existence, the practical difficulties of construction in each case, and the most promising means of overcoming those difficulties.

Let us first consider the advantages which Refracting Telescopes, of such sizes as are already in existence, possess over Reflecting Telescopes.

1st. *Inasmuch as the light lost by the double reflection in case of a Reflector is greater than the amount lost by transmission through an object glass of corresponding size, a Reflector to be of same optical power must be of greater diameter than a Refractor; consequently, it will be subject to greater atmospheric disturbance and will not be useable with as low a power as the Refractor.*

This is a most important point and worthy of attentive consideration; for, inasmuch as atmospheric disturbance is really the great limit to optical power—and a limit also which opticians and astronomers are powerless to modify—it seems evident that whatever direction enables us to advance our optical power with the least increase of atmospheric disturbance must be the most desirable. By-and-by, however, in considering the effect of increase of aperture, we shall see that this advantage of Refractors over Reflectors must diminish as the telescopes get large, and at some point not very far remote, must vanish altogether.

Let us consider this point a little further. Dr. Robinson, in "Philosophical Transactions," 1869, vol. 159, treats of this matter, and the result of his calculations may be given in a few words.

The light-grasping power of a Reflector may be expressed by the square of the aperture × a certain fraction which represents the proportion of the light reflected to that of the whole light.

This varies in various forms. In the Cassegrain, curious to say, the fraction is higher than in the Newtonian, and in the silver on glass mirrors considerably higher than in the metallic.*

In the Refractor the light-grasping power may be expressed by the square of the aperture × a fraction which represents the balance of light passed after absorption from the substance of each glass and reflection from the surfaces of each glass.

It is evident from the foregoing that the light-grasping power of a unit of surface of a Reflector is independent of the size, while in a Refractor it diminishes as the size increases, on account of the extra absorption of light, from the extra thickness of glass. Dr. Robinson estimates, from experiments made with the best existing kinds of glass, that a Refractor of 35·435 inches would be just = a Reflector of same size (metallic), but that beyond this size the Reflector would have the advantage.

The next point of advantage of Refractors we have to consider is that of—

2nd. *The greater permanence of collimation and consequent suitability for ordinary observatory work and measuring purposes.*

This is, no doubt, a considerable advantage of the Refractor, particularly if it is intended that the instrument should supply the place and do the work generally allotted to the great Equatorial Reflectors placed in our large observatories. It is, however, most probable that any telescopes constructed in future of larger dimensions than those at present in existence will have such special work allotted to them as will render them quite independent in this matter. This defect (if it may be called such) arises from the impossibility of supporting large Reflectors rigidly in their cells, either as regards their back or lateral supports. The defect becomes, of course, more apparent in large size telescopes, but can probably be much reduced by slight modifications of the supporting systems. For instance, I have found great advantage in grinding the back of the mirror to a convex curve with radius = that of the face + thickness of disc. Any error in collimation is thereby much reduced.

It is quite possible and even probable that if the size of Refractors be much increased, the errors of collimation may become, even in their case, of serious quantity. As to comparing the relative qualities of Reflectors and Refractors as regards suitability for ordinary measuring purposes, it seems to me quite unnecessary, as this work is capable of being done, and done efficiently, by smaller instruments, and any measurements likely to be useful for such monster telescopes would only be those differential measures taken by means of micrometers, which errors of collimation, &c., do not affect.

* I refrain from giving any actual figures here because there is much difference of opinion thereon, and I hoped that before this paper was read that the Photometrical Committee of the British Association would have come to some reliable conclusion on the subject.

3rd. The next advantage of Refractors we have to consider is that of the *Greater permanence of the optical portion.*

This is an advantage the weight of which much depends upon local circumstances. If the telescope was to remain the property of, and to be worked by the person who completed the optical part (as in the case of Lord Rosse, and Mr. Lassell, and Mr. Nasmyth), this disadvantage of Reflectors would not have much weight; and it is for this reason, probably, that it has been remarked (and with some truth too) that Reflectors very seldom do good work except in the hands of their makers. If, however, the telescope is to be sent to a foreign country this point becomes worthy of serious attention, and its advantage becomes more and more decided as the situation of the telescope becomes more and more inaccessible. There are then only the following safe methods of managing a Reflector:—In any case there should not be less than two mirrors. If it be a metallic mirror, either a person should be sent out with the telescope duly instructed in the art of figuring the mirror, or a relay of several mirrors, three or four (according to position of observatory and time taken to reach it), should be provided, and each mirror as it becomes tarnished, sent back to the maker to repolish; or, in the case of a silvered glass mirror, apparatus should be provided and a suitable operator permanently appointed to resilver the mirrors whenever required; which in large telescopes would be very often indeed.

It is not, however, to be taken for granted that all objectives are perfectly free from deteriorating influences. The 13-inch objective in Greenwich, I believe, requires periodic cleansing of its surface to free it from a peculiar tarnish which attacks the flint (probably the lead used in the flint has much to do with this); and we hear of object glasses which have lost a large per-centage of their transparency from this peculiar tarnish. As regards metallic Reflectors, there seems much difference of opinion as to their durability, arising probably from the fact that the liability to tarnish increases very rapidly as the quality of the alloy becomes "low," *i.e.*, as the proportional quantity of copper is increased above the true atomic proportion of four to one. A slight addition to the quantity of copper, though it may be hardly appreciable as to colour while the polish is fresh, increases enormously the liability to tarnish. I have seen a mirror whose polish was perfectly good after thirty years, though no very particular care was taken of it. As mirrors increase in size, however, of course the difficulties of preserving them become much greater; but it would be fair to assume that a large speculum of good alloy should, in a good climate, stand two or three years' constant work before requiring repolishing, and by our present system of polishing, it is possible to repolish mirrors, without any necessity for refiguring, with almost absolute certainty.

As regards silver on glass mirrors, it is hardly worth discussing their relative powers of permanence, as at the present date the art of glass-making has not arrived at that degree of perfection that will permit the makers to undertake discs of

any kind of suitable glass of six feet in diameter; but I may mention, that this is perhaps not to be much regretted, as the difficulty of preserving a silvered glass surface of large size would almost amount to an impossibility, and the process of resilvering, when the mirror is of large dimensions, becomes most formidable ; and, finally, it is probable that all the advantages of the silvered glass mirrors, without their corresponding disdvantages, may be secured by other means —a matter which I shall speak more of further on.

NOTE.—It may be remarked here that the bad conductivity of glass would render it very objectionable as a material for large mirrors. Professor Newcomb finds spherical aberration, arise from a slight difference of temperature of an objective only about four inches thick. How much greater would the effect be in case of a Reflector even of same thickness. (The effect would be fully four times as great as in a Refractor). Also, in consequence of the very perfect reflection of heat rays from the silver surface, the mirror is almost certain to *dew* every time the temperature of the air is lowered, and in large mirrors this dewing involves rapid destruction of the film of silver.

4th.—*General suitability for observatory work and measuring purposes.*

The same remarks apply to this as to the second point considered, viz., *the greater permanence of the adjustments of the refractor;* indeed to a considerable extent one arises out of the other. It is necessary, therefore, to say but few words on the matter.

It is not to be expected that very large telescopes are to supplant moderate sized instruments in what may be called the everyday work of an observatory ; such a course would be perfect waste of power; for if a telescope be completed of a size and power greater than hitherto attained, clearly every available moment should be made use of in using it for such objects and purposes as are beyond the reach of all other instruments ; and therefore this superiority of the Refractor is not to be considered of much weight in the case of very large instruments.

5th.—*In the Refractor there is no central mirror or arm to disturb the course of rays.*

There is no doubt that this has much to do with the difference of character of the image of a star as seen in Refractors and Reflectors.

If, while looking at a star in a Refractor, we cause a diaphragm of about one-sixth the diameter of the objective to be placed opposite its centre, we alter the character of the image to something very like that of the Reflector, excepting that we still have the secondary spectrum. It is difficult to describe the exact peculiarity, but those accustomed to the use of telescopes will understand what I mean. Which, then, is preferable ? Here we have a wide difference of opinion, and very conflicting ideas, which, however, on analysis, may prove not so widely differing as at first sight appears.

In the first place there is no doubt that good work has been done with both kinds of instruments ; secondly, in ninety-nine cases out of a hundred, it will be found that each observer will give his opinion as favourable to whatever kind of instrument he has himself been accustomed to work with.

In this will probably be found the secret and key to the whole difference of opinion. A veteran and well-known worker with Refractors declared "he never looked into a Reflector without drawing away his eye in disgust;" and workers with Reflectors cannot understand how the Refractor workers can bear that dreadful fringe of colour from the secondary spectrum. The same applies to other matters. Newtonian observers cannot understand how those who observe with Refractors or Cassegrain Reflectors can bear to strain their neck so in looking up through the tube; while the Refractor and Cassegrain workers cannot understand how the Newtonian workers will break their backs sitting or standing bolt upright, when they might be reclining comfortably on an easy chair as they do. After all, when this comes to be investigated it resolves itself into but little more than a question of to which telescope the observer has been most accustomed. Each observer becomes in time *wedded to his own instrument;* he has done his work with it, the credit of his discoveries is due to it, and he naturally falls into the idea that no other can be as good.

As regards the effect of the *arm* of the small mirror on the image, I do not think much advantage can be claimed in this respect. I use a small central mirror supported on a thin arm for illuminating the micrometer field in all our achromatic telescopes, and although I provide the means of instantaneously removing this in case the observer may think the perfection of the image is injured, I do not find that this is made much use of.

6th.—*Less effect from air currents in Refractors.*

The Refractor having a tube closed at both ends, and the Reflector being open at upper end, the condition of air currents is quite different in the two cases, to the disadvantage of the Reflector, for in it the upper end being open, there is nothing to prevent currents of hot and cold air up and down the tube, and in and out of the aperture, and for this reason great advantage has been found in ventilating the tubes, *i.e.*, making it of some open-work construction in order that the air may pass through and across and remove currents of differing temperatures. This difficulty is not felt with Refractors; but, curious to say, in the largest Refractor at present in existence (the Washington 26-inch), Professor Newcomb informs me that considerable inconvenience is felt sometimes from the outside of the object glass cooling down more quickly in the evening than the inside, which produces a decided effect on the spherical aberration and injures temporarily the otherwise fine definition. He consequently recommends the use of lattice or ventilated tubes for very large Refractors. If this be found necessary, this advantage of the Refractor vanishes.

I now come to the second part of my subject, viz., the advantages that Reflectors possess over Refractors.

B 1.—*Absence of Secondary Spectrum.*

Owing to the irrationality of spectra given by the flint and crown glasses at present obtainable, there remains always in the best corrected objective a little fringe of outstanding colour, technically called the "secondary spectrum." It is impossible to avoid this defect unless the glass manufacturers succeed in making glass of different optical qualities to that at present in use; "Gauss" in theory and "Steinhiel" in practice tried to unite the central rays with those of a zone near the circumference, but the form of the resulting objective became very impracticable, and the result was no better than the less complex forms. Professor Stokes and the late Mr. Vernon Harcourt tried a number of experiments with the view of obtaining two kinds of glass with rational, or nearly rational, spectra. These glasses I worked into an objective for Professor Stokes. The result was successful so far as the obtaining of specimens of phosphatic glass with rational spectra; but phosphatic glass is almost unworkable, and when the experiment was tried on a siliceous glass it failed. Some alleviation of this secondary spectrum can be obtained by using a triple objective, but with, of course, a corresponding loss of light.

It may, therefore, be assumed that at present there is no good prospect of any large objective being made without secondary spectrum, and, unfortunately, this increases very rapidly with increase of aperture of objective.

B 2.—*Applicability of Reflector for Physical Work.*

This is the great point of advantage which the Reflector possesses over the Refractor. The extraordinary strides made in Physical Astronomy of late years, and its still increasing importance, places this point of superiority in the very first rank for consideration, and this one point alone in many cases actually necessitates the adoption of the Reflector.

It was for this reason that, when furnishing the 15-inch Refractor for Dr. Huggin's use, the Royal Society, with admirable foresight, ordered me to adapt an 18-inch Reflector to the same mounting, and it is with this Reflector that Dr. Huggins has within the last few months obtained the photograph of the spectrum of α Lyræ, with which he has astonished the astronomical world, and which it would not have been possible to obtain with a Refractor.

It is needless to go through all the various points in which the Reflector has the advantage as regards physical work; they are well known, and are fully treated of elsewhere; suffice it to say that in all the branches of stellar spectroscopy, photography, and in thermometric experiments, the Reflector possesses great advantages, and in some cases the experiments can only be carried on by their use; and finally, *be it remembered, that these are just the very experiments to which a monster telescope should be, with greatest advantage, devoted.*

B 3.—*Possibility of supporting Reflectors with perfect freedom from flexure, irrespective of size.*

No matter what the size of the mirror may be there is neither theoretically nor practically any difficulty in supporting it perfectly free from flexure by using my father's system of levers.

It is not so with objectives. *It is* possible to support them so during polishing, but when in their tube they can only be supported round the edge, and it is possible to conceive a size of objective which could be polished and figured on the machine to perfection, but which could never be made to perform perfectly for want of uniform support when in its tube. Of course, this point is not necessary to be considered except in case of extension of size of telescopes much beyond that already existing.

B 4.—*General convenience of Instrument for observing purposes.*

The tube of the Reflector is much shorter than the corresponding Refractor, and if the Cassegrainian form be used, the circle swept by the eyepiece is very short indeed, so much so that in the case of the great Melbourne Telescope of four feet aperture the observer never required to be more than two or three feet off the ground, while in the case of a corresponding Refractor the observing chair or platform would assume ponderous dimensions, and the observer would sometimes find himself thirty feet off the ground. All these matters, although spoken slightly of by some as "mere mechanical difficulties, easy to be overcome," become very great inconveniences in practice.

We have now to consider how these various advantages and disadvantages are likely to be influenced by a large increment in the size of telescopes over those at present in existence.

Advantages of Refractor over Reflector. How influenced by increase of size.

Referring back to the same numbers I used before—

The 1st point of advantage of Refractors over Reflectors would appear to vanish when the objective attains a size exceeding 36 inches, and for objectives (if they be ever made) much beyond this the advantage would lie the other way.

No. 2.—This advantage of Refractors will probably increase in quantity with increase of size, but, for reasons stated before, the value of the advantage will probably be found to diminish.

No. 3.—This advantage undoubtedly increases with increase of size.

No. 4.—Need not be considered for reasons before stated.

No. 5.—Would not be affected by increase of size.

No. 6.—May probably, for reasons before stated, vanish in very large instruments.

Advantages of Reflector over Refractor. How influenced by increase of size.

B 1.—This advantage increases rapidly with increase of size, so much so that Dr. Huggins, when testing the 15-inch objective, thought at first it was over-corrected for achromatism, and Professor Newcomb, I believe, had the same experience when the great 26-inch objective was first tried. And this outstanding colour in the image will in large telescopes create a great inconvenience in all spectroscopic observations, as the star requires refocusing on the slit for every different ray of the spectrum.

B 2.—This point cannot be said to be influenced by increase of size, but the value of the advantage of the Reflector becomes undoubtedly much greater by such increase, when we consider the number of unresolved problems in Physical Astronomy, and that these are resolvable only by increase of optical power.

B 3.—This is a point which only comes into effect in large sizes.

A Reflector can be, as mentioned before, perfectly supported irrespective of size. Refractors can only be supported round their edge.

Up to 12 inches diameter I have found it possible to support objectives without flexure on three points round the periphery.

When, however, I tried 15 inches, I found decided flexure from the three points, and was obliged to introduce three intermediate levers of support, automatic in their action. With the 27-inch Vienna Refractor I expect I shall have to use six intermediate supports.

A question now arises, what is the greatest size which can be supported by edge support alone? For a point must sometime be arrived at, at which the weight of the glass will be sufficient either to distort the figure sufficiently to injure the definition, or to produce such a molecular strain as to polarize the light, and produce a double image.

Then arises another question: suppose this point arrived at, is there no remedy? Two such occur to me—

Firstly—A central support could be introduced with no worse effects than the central mirror in a Reflector; and

Secondly—A far more elegant contrivance would be to hermetically seal the tube (the lower end might be sealed by an equivalent to a low power Barlow lens), and fill the tube with air under such pressure as would support a sufficient portion of the weight of the objective on a perfect air cushion. Of course this pressure should be regulated according to the altitude of the telescope, but I have devised a mechanical contrivance for this purpose.

The pressure required would be very small. Suppose the objective to be forty inches aperture, and 600 lbs. weight, and that it was proposed to lift two-thirds of its weight on the air cushion, a pressure of about one-third of a pound on the square inch, or say one-fiftieth of an atmosphere, would suffice, even when the telescope is at its maximum elevation.

B 4.—All these matters of convenience mentioned before will be found to gain in importance as the size of the instrument is increased.

Now I come to consider *the practical difficulties in each case, and the most promising means of overcoming these difficulties.*

It may be said that the difficulty of manufacture is a question for the instrument-maker alone, and not to be discussed by those whose business it is to decide on the form of instrument employed, but it should be remembered that any advance in the size of Telescopes, Refractors or Reflectors, over those at present in existence, must be considered to be, to a certain extent, an experiment, and the nature of the difficulties which will be encountered, can at present only be speculated upon, even by the most experienced; and therefore it behoves those whose province it is to decide on the matter, to inquire diligently into the relative practicability of the various forms of telescopes in order that they may not decide on a form which might be, if ever accomplished, of great usefulness, but which on trial would be found to be, in the present state of art, impossible to manufacture.

With respect to Refractors, the first great difficulty to be met with is that of procuring suitable discs of glass. Of our glass manufacturers, only two firms seem to possess the secret of manipulation of optical glass, viz., Messrs. Chance, Brothers, and Company, of Birmingham, and M. Feil of Paris, a descendant of the celebrated Guinand. Of these, one at least speaks confidently of producing discs up to one metre in diameter; but when I consider the difficulty which I know was experienced in moulding the 27-inch discs for the Vienna objective, I cannot say that I feel the same confidence. These 40-inch discs would require to be obtained in one single piece just three times the quantity of homogeneous glass that the Vienna discs required, and though I am not of course in the secrets of the glass manufacturers, it appears to me that the chances of obtaining 40-inch discs in the present state of the art are remote.

The other difficulties of manufacture of Refractors consist in the nicety of the operations connected with the calculations of the curves, the manipulation of such extremely costly material, and the enormous labour and trouble of the figuring and perfecting of the objective. All these, however, I have no doubt will be overcome by the optician for any size which the glass-maker is at all likely to produce.

Now, as to the difficulties connected with the manufacture of Reflectors, whether metallic or silver on glass.

First, as to the difficulty of producing the metallic or glass disc to work upon.

Lord Rosse has succeeded years since in casting, annealing, and perfecting discs of six feet in diameter, and any difficulties he met with were not such as to lead us to the belief that the limit of possible size has been by any means reached. As regards glass mirrors, the question has never been discussed, for in any sizes that have been made up to the present time, it was only necessary to go to the plate glass manufacturers and say, "I want a disc of crown glass of such a diameter and

such a thickness," and forthwith the glass disc was delivered without any trouble; but, when we come to these extraordinary sizes, it is quite a different matter. For the 4-foot disc of glass for the Paris Reflector, in place of that which has so recently resulted in failure, the St. Gobain Glass Company require twelve months' time to perfect (although, be it remembered, the quality of the glass is here of no consequence whatever); and I have been myself in correspondence with the principal glass manufacturers here and on the Continent, and not one of them are willing to undertake even a 6-foot glass disc; so that it would appear that, above that size, the silver on glass mirrors are out of the question.

This much, however, is to be said—If anyone were to go to a brass or bell-founder's and ask them to undertake a speculum of six feet in diameter, they would almost certainly be met with a refusal; and yet Lord Rosse has proved the feasibility of it. And so, reasoning by analogy, might the manufacture of a six or eight foot glass mirror be possible, if undertaken in the same scientific spirit that Lord Rosse undertook his. I answer to this—Yes; perfectly true; but this is too purely a speculative matter to be considered at the present day in the choice of telescopes.

The other great difficulty in the manufacture of Reflectors is the annealing of the disc, and I believe it is this difficulty which limits to so narrow an extent the production of glass discs for silver on glass mirrors.

I should wish to say a few words on this matter of annealing.

Anyone who has studied the matter knows that if it were possible to ascertain how the disc of metal, which is built up in the oven, is cooling—what part is cooling quickly, what part is cooling slowest, and to have the power of controlling the rate of cooling of the different parts—that the problem of annealing a disc of almost any size would be solved. By a disc I mean a circular plate whose diameter bears a large proportion to its thickness.

But when the disc is built up with solid brickwork several feet thick, we cannot tell what is going on. It may be cooling quickly round the edge, and the centre in cooling *drags*, so to speak, from this solid ring on the outside, and either comes out of the oven cracked, or ready to crack at the first slight disturbance of its molecules; or a draught of air may be creeping in between chinks in the bricks, and doing mischief.

In the case of the Melbourne Reflector the Rev. Dr. Robinson proposed the introduction of a small thermo-pile into the oven, which enabled us to get the rate of cooling, and enabled me on one occasion to detect a draught of cold air from a crack in the bricks, which if undetected might have caused the loss of the mirror.

I shall now in a few words describe the method I would propose for the annealing of large discs either of glass or speculum metal.

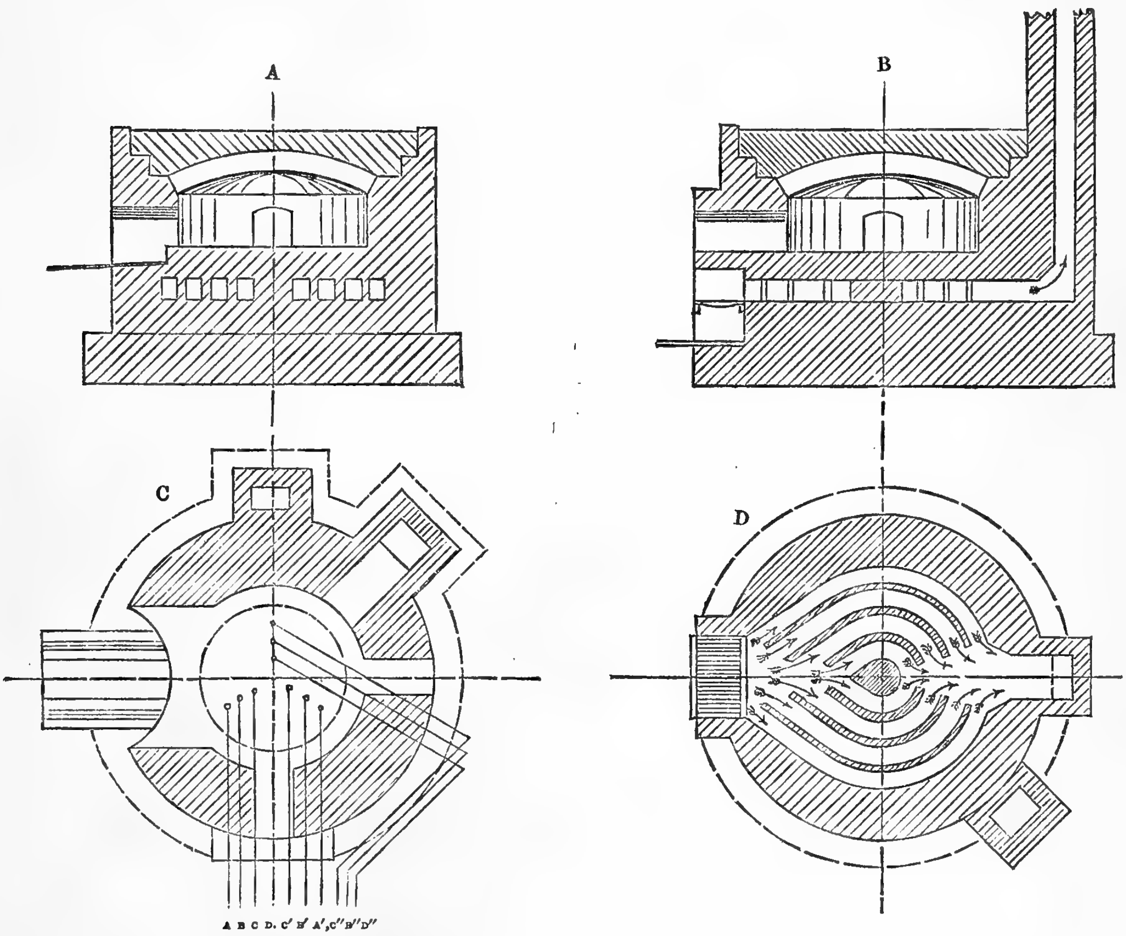
The figures A B C and D represents vertical and horizontal sections of an oven very similar to that used for annealing the Gt. Melbourne mirrors, slightly modified, however, to suit the larger sizes.

The lower story, D, is constructed with a large fire area and a set of nearly semi-circular flues, any one of which can be used or stopped at pleasure, and thus a means is given of modifying the heat of any portion of the floor of upper oven in which the speculum or glass is placed.

In the second story, C, is placed the speculum or glass, and lying on it are the extremities of 10 thermo-electric couples. These are supposed to be all rated beforehand, so as to give equal deviations of the magnetic needle for equal temperatures, or if not, their scales should be known.

One of these couples is placed lying on centre of mirror, the others are arranged in three sets, 120° apart, and at different distances from the centre, so that the mean of reading of three couples equally distant from centre will give a fair estimate of the relative heat of that zone of mirror to the other zones thus—A.A′A″ : B.B′.B″ : C.C′.C″ : D—will give the proportional heats of the 1st or outer zone to the 2nd, 3rd, and centre.

The relative rates of cooling of different parts being thus known, the heat can be modified by allowing heated air or cold air to pass through the various flues.



I mentioned above that I would speak subsequently respecting a method of

securing the advantages of silvered glass mirrors without their corresponding disadvantages.

I am not as yet in a position to disclose the exact nature of the improvement by which this is effected, but I have reason to believe from experiments that I have made, that we shall be able in some little time to produce metallic mirrors with a reflective power of at least 25 per cent. over those formerly made.

Should this result be attained, it will reduce the size of Reflectors of corresponding power to considerably less than before stated, and modify the several advantages of Refractors mentioned above to a considerable extent.

With respect to the mounting of very large telescopes, I have had so much to say on the optical part that I wish to make any remark on the mounting as short as possible. Suffice it to say, that I do not see any insuperable difficulties in the mounting of such telescopes as we have here been treating of on equatorials similar in principle to those we use at present, taking the Vienna as a type of Refractor mountings, and the Melbourne as a type of Reflector mountings—subject, of course, to modifications necessarily entailed by the increase of weight; and as I am, and always have been, a strong advocate for making the observer as comfortable as possible (believing that thereby his capacity for useful work will be increased), I would strongly advocate in very large telescopes that hydraulic power be utilized for conducting all the laborious operations, so that the observer, without moving from his chair, might, by simply pressing one or other of a few electrical buttons, cause the telescope to move round in right ascension or declination, the dome to revolve, the shutters to open, and the clock to be wound. This is no mere Utopian idea. Such things are done, and in common use in many of our great engineering establishments, and it is only in the application that there would be any difficulty encountered.

And now, in conclusion, I would say that I have endeavoured to discuss *all* the various points of superiority of each kind of instrument over the other as they have occurred to me, and I do not think any more of importance will be found; and I expect it will be seen, that I have done so without advocacy of any particular form, but with a desire that the relative weight of all their advantages and disadvantages should be appreciated.

If any present have followed my reasoning they will probably come to the conclusion that no one kind of telescope is *best* for all kinds of work, and that in the choice of telescopes reference must be made to the work the instrument is intended for, its geographical and even political position, and many other matters which it would not be possible to discuss in a scientific paper.

[NOVEMBER, 1877.]

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OF THE

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VOLUME I. (NEW SERIES).

MEMOIR No. 2.

ON THE PENETRATION OF HEAT ACROSS LAYERS OF GAS.

BY

G. JOHNSTONE STONEY, M.A., F.R.S.,

SECRETARY ROYAL DUBLIN SOCIETY.

[READ BEFORE THE SOCIETY, 21ST MAY, 1877.]

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ON THE PENETRATION OF HEAT ACROSS LAYERS OF GAS.

BY

G. JOHNSTONE STONEY, M.A., F.R.S., &c., Secretary Royal Dublin Society.

[Read 21st May, 1877.]

Part I.—Theory.

1. Heat will pass between bodies at different temperatures by direct contact, by radiation and absorption, or by contact with a fluid and convection through it. That heat may be transported in these several ways has long been known, and the laws of the transfer have been made the subject of repeated and careful investigation by experiment and by the deductive method. And last year two papers* were published by the author of the present memoir, in which it was shown that heat will also escape, under new conditions, across a Crookes's layer, if the layer be restricted in width. In those papers the mechanical actions that arise, and upon which Mr. Crookes had made many experiments, were made the subject of study; and the present communication aims at extending the investigation to the second branch of the subject, viz.:—The transfer of heat which accompanies those mechanical actions.

2. When gas is in contact with a body A at a different temperature from itself, it is a familiar fact that convection currents rapidly set in. The first step of the process is the almost instantaneous formation of that layer which I have called Crookes's layer—a layer of the gas of varying density and temperature, being on one side at the temperature of the body A, and on the other side at the temperature of the surrounding gas. It is because this layer has a different density from the rest of the gas, and because of the attraction of the earth, that those streams set in which are called convection currents; and accordingly, if the experiment could be made at a station where there is no gravity, these convection currents would not arise, although the Crookes's layer would then also be fully developed. It will be convenient to inquire first what will occur under these simplified conditions, and afterwards to take into consideration whether any modification has to be made to allow for the effect of the neighbouring earth. To give to the problem definiteness and the utmost simplicity, I will suppose that a body A at temperature θ_1, presents a large flat surface to an atmosphere of gas which is at a lower temperature θ_2, and exposed everywhere to a constant pressure, but which is uninfluenced by gravity. Let us further regard this gas as a perfect non-conductor of heat.

3. If the excess of temperature is supposed to be *suddenly* imparted to A, there will be a brief interval of adjustment within the gas, after which the condition of the gas will settle down into the state in which the Crookes's layer will have been

* See *Phil. Mag.* for March and April, 1876.

fully formed. The Crookes's layer in this case will obviously consist of a flat stratum of the gas in contact with the hot surface of A: and within this stratum the temperature will gradually decrease from within outwards, from θ_1, the temperature of A, down to θ_2, the temperature of the surrounding gas. This gradual falling off of the temperature implies a corresponding gradual augmentation of the density, since we have supposed the gas to be everywhere subjected to the same pressure. If the gas *could** admit of the formation of a *complete* Crookes's layer, then we know from the familiar experiments which show gases to be bad conductors of heat, that, after the brief interval of adjustment, a permanent state would ensue, in which there would be no further change of density, or motion of heat except by radiation. Accordingly, if an isothermal surface be now drawn within the layer (which, in the simple case we have supposed, will be a plane parallel to A), there will fly the same number of molecules per second in both directions, across an element δS of this surface, the momentum of the two processions which pass through δS in a second will be the same, and their kinetic energy also will be the same. Their number will be the same, for otherwise the density would be still undergoing change, and we have supposed that the period of adjustment is over; their momentum will be the same, because the pressure is everywhere constant; and their kinetic energy is the same because there is no transfer of heat across S.

4. Hence, the change of temperature and density in passing along δx, an element of the normal to δS, must be such as to secure these three conditions. In investigating the law of this variation, we have to take into account—

P, the pressure everywhere through the gas;
θ, the temperature measured from absolute zero, on the isothermal surface S;
ρ, the density of the gas on the isothermal surface S;
x, the distance of S from A; and
G, a quantity which changes from one gas to another, but is almost constant in each gas, within a wide range of temperature and pressure.

When the gas and its tension are given, G and P are constants; and ρ is a known function of G, P, and θ; hence only two of the foregoing quantities are independent, suppose θ and x; instead of which we may use $\frac{dx}{d\theta}$ and θ. It is easy to see, by taking particular instances, that $\frac{dx}{d\theta}$ and θ will remain independent of one another, if only two of the conditions in §. 3 need to be fulfilled, but if all three have to be fulfilled, we find by experiment, that a definite Crookes's layer is formed, and that, therefore, in each gas and at each pressure $\frac{dx}{d\theta}$ is a definite function of θ. In other words—

$$\frac{dx}{d\theta}=\psi(\theta, G, P) \quad . \quad . \quad . \quad . \quad (\alpha),$$

* See next page, the last paragraph of section 4.

in which G and P are constants. This furnishes by integration an equation of the form—

$$x = \text{const.} + \phi\ (\theta, G, P) \quad . \quad . \quad . \quad . \quad (\beta),$$

which represents the law by which the temperature must change across the layer. What we learn from this investigation is, that besides the uniform distribution of a gas with the same temperature everywhere, there is one other permanent distribution possible (except at the limits), and perhaps only one; that in it there is, for each gas and at each tension, a definite gradient of temperature, with its accompanying equally definite gradient of density in the opposite direction. These results might have been arrived at in another way, viz., by a consideration of the effects of the inter-molecular encounters.

Another case in which the three conditions will be fulfilled is the familiar one of a *uniform* medium, in which case—

$$\frac{d\theta}{dx} = 0, \text{ or } \theta = \text{const.} \quad . \quad . \quad . \quad . \quad (\gamma).$$

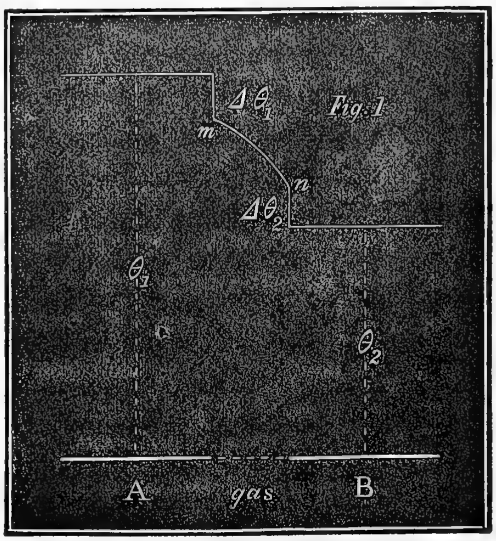
But if there is a transition from one of these solutions to the other, as there must be where the Crookes's layer is in contact with the rest of the gas, there will be an interval of compromise, in which the three conditions are not strictly fulfilled. Similarly, they cannot be fulfilled where the Crookes's layer adjoins the hot body A. Hence there must, in the cases that really arise, be some escape of heat, which may be small, but cannot vanish, because discontinuity is impossible, since the length of the mean path of a molecule between its encounters with other molecules is finite. Hence, also, the values of the temperature at different depths within the Crookes's layer will differ by small amounts from those assigned to it by equation (β). It will appear, however, from the next paragraph, that the rate of cooling arising from these imperfections will be very slow,* and although the heat that passes would doubtless accumulate and ultimately become considerable if there were no gravity, its presence will be inappreciable in most of the experiments we can make, where the portion of gas in which the Crookes's layer is formed is being constantly renewed by convection currents.

5. We have hitherto supposed that the atmosphere of gas was of sufficient extent to allow the whole of the Crookes's layer to come into existence; but we shall have entirely new conditions if a body B at temperature θ_2, which for simplicity we may suppose to have a large flat surface, is placed parallel to A at a distance less than the thickness of an unrestricted Crookes's layer. In this case a *compressed*† Crookes's layer will come into existence, in which, as explained in §. 16 of my former papers, the density of the gas must be everywhere greater than at the same distances from A in the complete Crookes's layer, to preserve the lateral pressure

* For, the Crookes's layer being in this case almost complete, the values of $\Delta\theta_1$ and $\Delta\theta_2$ (see §. 5) will be exceedingly small.

† *i.e.*, a Crookes's layer confined between the heater and cooler, against which the layer of gas expends its Crookes's stress. In withstanding this stress the heater and cooler compress the layer.

unchanged. Through each element δS of an isothermal surface, the molecules will still travel in equal numbers inwards and outwards, because when the adjustment is once over, the density of the gas will not anywhere undergo further change; but the molecules making their way outwards, *i.e.*, from A towards B, will on the whole be swifter than those tending inwards, because there should be a *complete* Crookes's layer to enable the swifter class of molecules rebounding from A to keep back the whole of the slower kind which constantly tend to crowd in (see *Phil. Mag.*, April, 1876, p. 308, §§. 15, 16, and 17). Accordingly, if the molecules at any one moment within an element of volume be considered, the portion of them which form a procession travelling inwards will now be found more numerous than those advancing outwards, and at the same time so much slower that the momentum in the two directions is the same; in other words, there is no molar motion of the gas, nothing in the nature of a wind. But that there is a continual transfer of kinetic energy from A to B across the intervening gas is evident, because members of the procession of colder molecules crowding up to A will cause the temperature $\theta_1 - \Delta\theta_1$ of the inner surface of the Crookes's layer to be lower than θ_1, the temperature of A; while, at the same time, the members of the swift procession which reach B will cause $\theta_2 + \Delta\theta_2$, the temperature of the outside surface of the Crookes's layer, to be warmer than θ_2, the temperature of B. The Crookes's layer, accordingly, must acquire heat by its contact with A, and impart heat where in contact with B; and as adjustments within the layer are made with a speed comparable with the velocity of sound in the gas, it is possible to arrange experiments in which the differences of temperature $\Delta\theta_1$ and $\Delta\theta_2$ shall have any amounts from 0 (when the interval between A and B equals or exceeds the width of an unrestricted Crookes's layer) up to values bordering upon $\frac{1}{2}(\theta_1 - \theta_2)$, (which, in the cases where the temperatures θ_1 and θ_2 are not far asunder, is close to the limiting value produced by diminishing the interval between A and B, or by attenuating the gas).



Accordingly, if the variations of temperature were plotted down on a diagram, the ordinates representing temperatures, and the abscissas distances measured perpendicularly to the isothermal surfaces within the gas, we should obtain a figure something like that in the margin. It is, moreover, manifest that the curve $m\,n$, representing the variations of temperature across a compressed Crookes's layer, will approximate more and more to a horizontal line, the greater the tenuity of the gas.

6. Some idea will be formed of the quantity of heat which will pass from A to

B by the process here described, and for which I would suggest the name *penetration*, by forming an expression which aims at roughly representing the quantity of heat absorbed by the gas per second from a square centimetre of A. One such expression is approximately—

$$\frac{dQ}{dt} = V\sigma\rho_1 \frac{\Delta\theta_1}{\theta_1} \quad . \quad . \quad . \quad . \quad . \quad (\delta),$$

in which V is the velocity with which the adjustment is made, σ the heat which would raise a gramme of the gas one degree in temperature, and ρ_1 the density (referred to water) of the gas, where it is in contact with A.

To get the loss by penetration per second from the whole surface of the cooling body, we have to find the value of the integral $\int \frac{dQ}{dt} dA$, dA being an element of the surface of the cooling body, and $\frac{dQ}{dt}$ having the value assigned to it above. If the surface is everywhere equally exposed, a condition easily secured in making experiments with thermometer bulbs, this becomes simply $A\frac{dQ}{dt}$, or—

$$AV\sigma\rho_1 \frac{\Delta\theta_1}{\theta_1} \quad . \quad . \quad . \quad . \quad . \quad (\epsilon),$$

where A is the area of the surface of the cooling body.

7. It will be instructive to compare the loss of heat by penetration with the quantity which is carried off by convection. To estimate the latter, let Ω be the section of the convection current, ρ its average density, $\Delta\theta$ the average excess of its temperature, and v its velocity. Then the total quantity of heat which will be removed per second by convection will be—

$$\Omega v\sigma\rho \frac{\Delta\theta}{\theta} \quad . \quad . \quad . \quad . \quad . \quad (\zeta).$$

This to be compared with (ϵ) the expression for the total loss of heat per second by penetration.

Now, in the cases that occur in laboratory experiments, $A\sigma\rho_1$ is seldom many times larger or many times smaller than $\Omega\sigma\rho$, but V is always very much larger than v, whence (ϵ) may have a value comparable with (ζ), while $\Delta\theta_1$ is very much less than $\Delta\theta$; in other words when the processions between the opposed surfaces have but slightly different velocities. We learn from this that the escape by penetration may be expected to manifest itself as soon as the Crookes's layer has become in a moderate degree compressed.* It is also evident that the co-existence of a convection current will not much affect the escape of heat by penetration, inasmuch as convection currents are sluggish when compared with the promptness with which re-adjustments are made in Crookes's layers. It is therefore worth while to examine the numerous records of experiments upon the velocity with which bodies cool in gases, with a view to finding whether instances of the escape of heat by penetration can be found among them.

* Hence, also, thermal experiments may be expected to explore Crookes's layers with more sensitiveness than contrivances for manifesting the mechanical force which is also present.

PART II.—INTERPRETATION OF EXPERIMENTS.

8. Accordingly, I made a search of this kind last year, shortly after the publication of my two papers in the *Philosophical Magazine,* but without finding any records more to the purpose than those by Dulong and Petit of experiments with hydrogen, which will be cited below; and as these, taken by themselves, did not seem sufficiently decisive, I postponed publishing further on the subject, until I should have leisure to make experiments myself. But before this leisure came, Mr. George F. Fitzgerald met with a brief notice in Jamin's "Physique," of experiments by De la Provostaye and Desains, which appeared to him to contain observations on the penetration of heat; and on referring to the original memoirs, published more than thirty years ago in the *Comptes Rendus,* I had the pleasure of finding the record of two elaborate experimental investigations into what we now know to have been the penetration of heat. At that time the experimental results were regarded as anomalous, and the only conjecture which De la Provostaye and Desains put forward is that they may in some way depend on the swiftness of convection currents in attenuated gases.* It is, however, easy to see that no such increased swiftness as can exist will account for the observed phenomena. Mr. Fitzgerald was unable to spare the time necessary to follow up the subject, or he would have joined me in working out this part of the present memoir; but to him is due the whole credit of having perceived the importance of these observations, and to his kindness I owe the advantage of having had my attention directed to them, and the permission to make use of them, as I now do.

9. Dulong and Petit, experimenting with a large thermometer bulb placed at the centre of a hollow copper globe, 30 cm. in diameter, blackened on the inside and kept at a constant temperature, observed the rate at which the thermometer, after having been warmed, cooled in different gases, at different tensions, and with the bulb naked or coated in various ways. From these experiments they obtained their well-known empirical law for the escape of heat by radiation and convection. The expression which they give consists of two terms, of which one represents the velocity with which heat escapes by radiation, and the other the velocity with which it escapes by convection, or, as we shall presently see, in some cases by convection and penetration. We have here no concern with the first of these two terms, further than to observe that the escape by radiation is the same at all tensions of the gas, and for all dimensions of the receiver, and depends only on the character of the surfaces exposed, on θ_2 the temperature of the copper globe, and on $\theta_1 - \theta_2$ the excess of temperature of the thermometer. For given values of θ_1 and θ_2 it was accordingly a constant at all the tensions, and with all the receivers which De la Provostaye and Desains used, and in the following diagrams

* See note A. at the end of this memoir.

is represented by the interval between two horizontal lines. This interval is, moreover, small, because De la Provostaye and Desains reduced the loss by radiation to a very small amount by silvering or gilding the bulbs of their thermometers.

The other term of Dulong and Petit's expression which furnishes the rate of escape by convection is—

$$K\,p^c,$$

where p is the tension measured in millimetres of mercury, K depends on the gas and on θ_1 and θ_2, and c was found to be nearly $\frac{1}{3}$ when the receiver contained hydrogen, but was nearly $\frac{1}{2}$ for the other gases experimented on and for atmospheric air. I will return to the case of hydrogen; but in the other gases the velocity of the escape of heat by convection with given temperatures of the bulb and receiver will be represented at different tensions of the gas by the ordinates of a curve not differing much from a parabola, since this would be the curve if the index were exactly $\frac{1}{2}$; and accordingly, curves of this kind are laid down in the annexed diagrams. It is not material whether a large or a small portion of the parabola is introduced, because all parabolas are similar.

10. By thus plotting down the results of the experiments upon diagrams, we obtain the means of seeing at a glance how much of the escape of heat observed by De la Provostaye and Desains can be accounted for by radiation and convection, and how much remains to be allotted to penetration. De la Provostaye and Desains made their observations in three receivers—a hollow sphere of 24 cm. diameter, a hollow sphere of 15 cm. diameter, and a cylinder* 6 cm. in diameter and 20 cm. in height. They, unfortunately, do not record† the sizes of their thermometer bulbs, so that the exact intervals between them and the walls of the containing vessels cannot be known. But it is likely that the thermometers were of about the same size as those they used in other similar investigations, and we shall, probably, not be far wrong in attributing to them a diameter of 3 centimetres. If this may be assumed, the interval between the bulbs and the walls of the receiver, would be—

$10\frac{1}{2}$ cm. in the largest receiver,
6 cm. in that of intermediate size, and
$1\frac{1}{2}$ cm. in the cylinder.

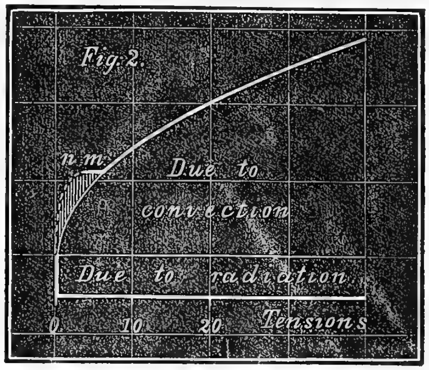
In Dulong and Petit's experiments the diameter of the receiver was 30 cm., so that the interval was about $13\frac{1}{2}$ cm.

11. With atmospheric air in their largest receiver (that with an interval between the bulb and the receiver of about $10\frac{1}{2}$ cm.), De la Provostaye and Desains found that the rate of cooling, or the escape of heat per second which is proportional to it, was represented by Dulong and Petit's expression (which had been based on experiments made with an interval of about $13\frac{1}{2}$ cm.), until the exhaustion

* The direction in which the heat penetrates, and of the Crookes's stress, will be perpendicular to the isothermal surfaces within the gas in the simple case which we have hitherto considered, where A is parallel to B; but it will in general pierce the isothermal surfaces obliquely if one part of the Crookes's layer is more curtailed than another.

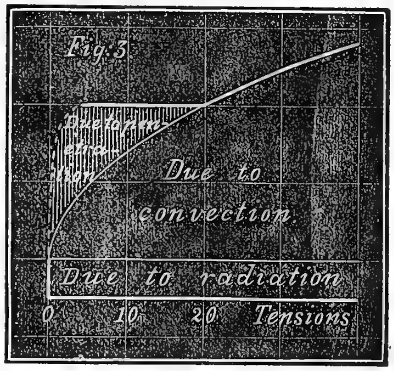
† They give this information in the *Annales de Chimie*. See note B at the end of this memoir.

reached 6 mm. of mercury; but that after passing that tension, the rate of cooling, instead of continuing to decrease, remained sensibly constant between tensions of 6 mm. of mercury and 2·8 mm., the lowest tension at which they experimented. This is represented on figure 2 by the horizontal line from *m* to *n*. In this figure the abscissas represent tensions in mm. of mercury, and the ordinates of the thick line represent the observed rates of cooling at different tensions, but with constant values of θ_1 and θ_2. The part of the ordinate between the horizontal lines represents the escape by radiation, its continuation up to the parabola represents the escape by convection, and the extension upwards into the shaded portion of the figure is due to the penetration of heat across the Crookes's layer which evidently reached the walls of the receiver when the tension was reduced to about 6 mm., and was compressed when the exhaustion proceeded farther.



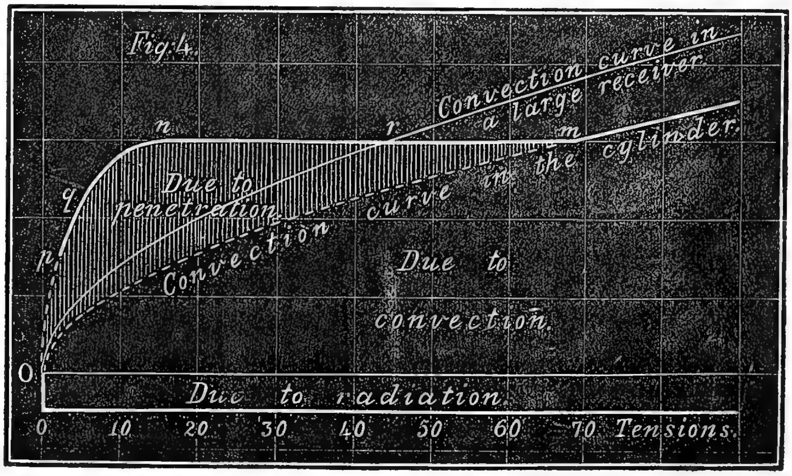
The shaded part is to be attributed to penetration.

Similarly with the receiver of intermediate size, in which a Crookes's layer of a width of 6 cm. would reach the walls, the results obtained by De la Provostaye and Desains are represented graphically by figure 3. In this case heat leaked away by penetration in appreciable quantities at tensions under 20 mm. of mercury, and kept the total escape of heat nearly constant between tensions of 20 and 4 mm.

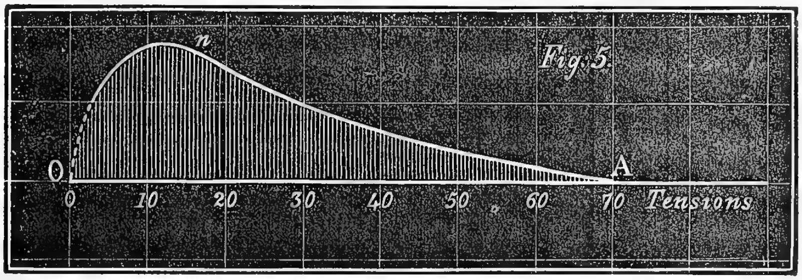


12. But the most decisive experiments were made with the cylindrical vessel, which was the smallest of the three receivers. In it the interval between the bulb and the walls of the vessel was probably only $1\frac{1}{2}$ cm.

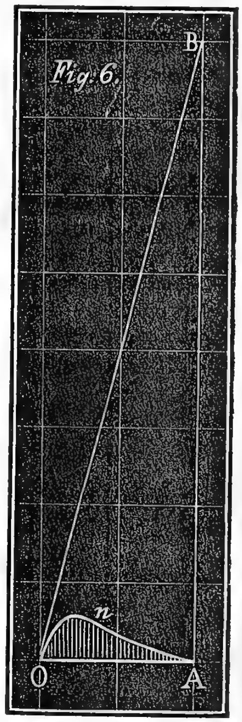
With this vessel the rate of cooling was *slower* than in the two larger receivers at all tensions from 760 mm., or the tension of an atmosphere, down to about 45 mm. This seems to indicate that the convection currents were impeded by the form and small size of the cylinder; so that if the ordinates of the parabola O*r* represent the rate of cooling which would result from convection in a large vessel, the ordinates of some smaller curve such as



Om will represent the rate due to convection in the cylinder. The observations recorded by De la Provostaye and Desains enable us to fix the points m, r, and n, corresponding to the tensions 70, 45, and 15 mm., nearly in a horizontal line. They also state that near the tension of 6 mm. the rate of cooling diminished with "excessive rapidity," but that nevertheless at a tension of 2·8 mm. it still exceeded by a large amount that which presented itself at the same tension in their largest receiver, and which is represented in figure 2. These statements indicate that the observations, if plotted down, would have given a curve like the thick line of figure 4. It is hardly necessary to point out that the larger development of the phenomenon and its exhibiting itself at higher tensions with each diminution of the size of the receiver, as shown in the foregoing diagrams, are in the most satisfactory accordance with the theory presented in this memoir.



13. If we suppose the shaded portions of the ordinates in fig. 3 to be moved vertically downwards till they abut upon a horizontal axis of abscissas, we shall obtain the curve in fig. 5, the ordinates of which represent the rate at which heat escaped by penetration in De la Provostaye and Desains' cylinder, separated from the effects of radiation and convection.



We can only compare this figure in a very general way with the formula given above for the escape of heat by penetration, viz.—

$$\frac{dQ}{dt} = V\sigma\rho_1\frac{\Delta\theta_1}{\theta_1} \quad . \quad . \quad . \quad . \quad . \qquad (\delta),$$

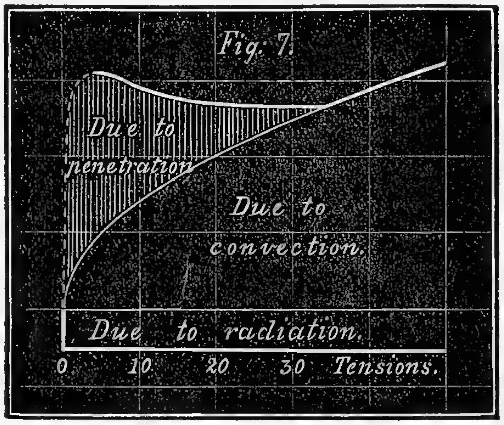
because too little is known of V, ρ_1, and $\Delta\theta_1$ to enable us to plot down a curve from this expression.* But we can, at all events, see that V will be only moderately affected by alterations of tension, that ρ_1 will vary nearly as the tension, and that as the tension is diminished, $\Delta\theta_1$ will gradually rise from 0 to a value which is nearly $\frac{1}{2}$ $(\theta_1 - \theta_2)$. Hence, the curve must be one somewhat like that of fig. 6†, whose ordinates first rise gradually to a maximum at a certain tension, after which they fall away to cypher, if the exhaustion is continued indefinitely. This description agrees with the form determined from the observations and which is plotted down in fig. 5; so that the comparison, though

* Just as the parabolic curve of convection could not have been plotted down from equation (ζ) § 7, owing to the vagueness of some of the quantities which appear in it, viz., Ω, v, and $\Delta\theta$.

† In fig. 6, OB is intended to represent a portion of the curve $y = V\sigma\rho_1\frac{1}{2}\frac{\theta_1 - \theta_2}{\theta_1}$, and OnA the result of shortening its ordinates in the ratio $\frac{\Delta\theta_1}{\frac{1}{2}(\theta_1 - \theta_2)}$.

necessarily very imperfect, lends support, so far as it goes, to the conclusion that the apparently anomalous escape of heat which De la Provostaye and Desains investigated was due to penetration.

14. Hitherto I have used only the observations recorded in a memoir published in the *Comptes Rendus,* vol. xx. (1845), p. 1767. In a second memoir published in the *Comptes Rendus,* vol. xxii. (1846), p. 77, De la Provostaye and Desains record observations made with a silvered thermometer within a blackened cylinder, which appears to have been of the same size as that used in the former investigation, and which they charged successively with hydrogen, carbonic anhydride, protoxide of nitrogen, and a mixture of air and hydrogen.



In carbonic anhydride the results of experiment are represented by fig. 7.* In this gas the total rate of cooling increased when the tension was diminished from 12 to 4 mm. This observation took De la Provostaye and Desains so much by surprise that they repeated and varied their experiments, till they were fully satisfied that the existence of the increased escape of heat was proved.

With protoxide of nitrogen (N_2O), a gas which has the same specific gravity as carbonic anhydride, their observations gave similar results. Between tensions of 35 mm. and 12 mm. the total rate of cooling remained nearly constant, and, as in carbonic anhydride, it was slightly increased by further diminishing the tension from 12 down to 4 mm. This slight increase was less in the protoxide of nitrogen than in the carbonic anhydride: about $\frac{1}{24}$th of the whole amount in the former gas, about $\frac{1}{12}$th in the latter.

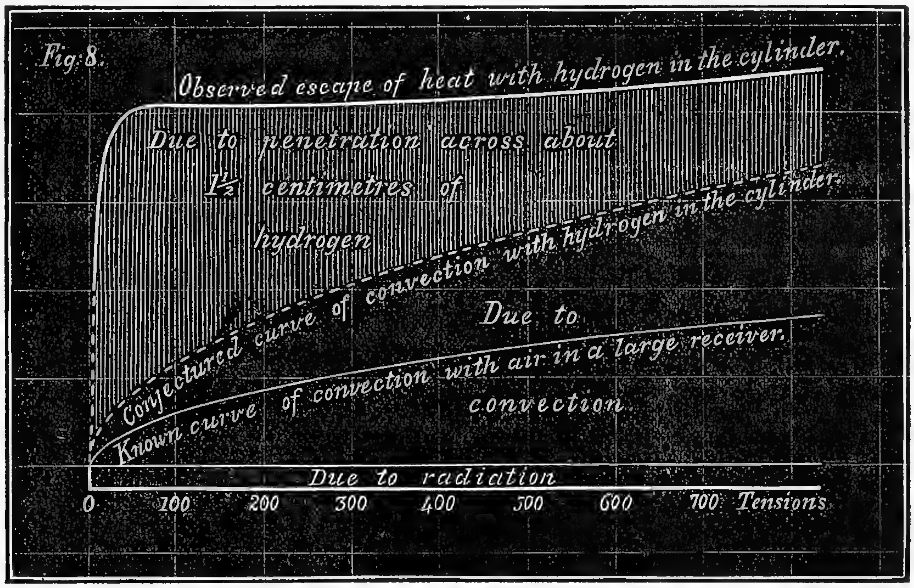
The observations with these gases show that the form of the curve represented in fig. 5 is in an appreciable degree different in different gases, and that there are some gases in which the increase of the escape of heat by penetration when the tension is decreased will, within certain limits of temperature, exceed the decrease of the escape of heat by convection.

* De la Provostaye and Desains record the following observations, from which the curve in the text has been plotted down, the ordinates being drawn proportional to the reciprocals of the observed times of cooling:—

Tensions, .	35 mm.		12 mm.		4 mm.	
	m.	s.	m.	s.	m.	s.
Times, . .	19	42	19	38	17	59

The reciprocals are proportional to 282, 283, and 309. The thick line in fig. 7 is not quite correctly drawn: it should have been almost horizontal between 12 to 35 mm.

15. We now come to the very remarkable results which were obtained with hydrogen. They are plotted down in fig. 8. A table of some of the results of the observations, and the following particulars recorded by De la Provostaye and Desains enable us to construct this figure. The loss of heat by radiation from the silvered bulb was only $\frac{1}{18}$th of the whole amount (presumably at 760 mm. tension). The rate of cooling at 20 mm. tension was found to be $\frac{11}{12}$ths of that at 760 mm. The rate of cooling at a tension of 12 mm. was rather more than $\frac{11}{12}$ths of that at 20 mm. At 4 mm. it fell to about one-half, and, nevertheless, when the rate of cooling at this lowest tension was compared with that of a similar bulb placed in



the open air, it was found to exceed the latter in the proportion of 4 to 3. We thus get from the observations* all parts of the figure except those entered in dotted lines. The curve representing the loss by convection must lie everywhere below the upper line of the figure, and probably lies considerably above the curve representing the loss by convection in air. It, therefore, occupies some such position as the dotted line of the figure. The shaded interval between this dotted line and the upper line of the figure represents the enormous escape of heat to be attributed to the penetration of heat through one or two centimetres of hydrogen.

* The following observations are recorded by De la Provostaye and Desains :—

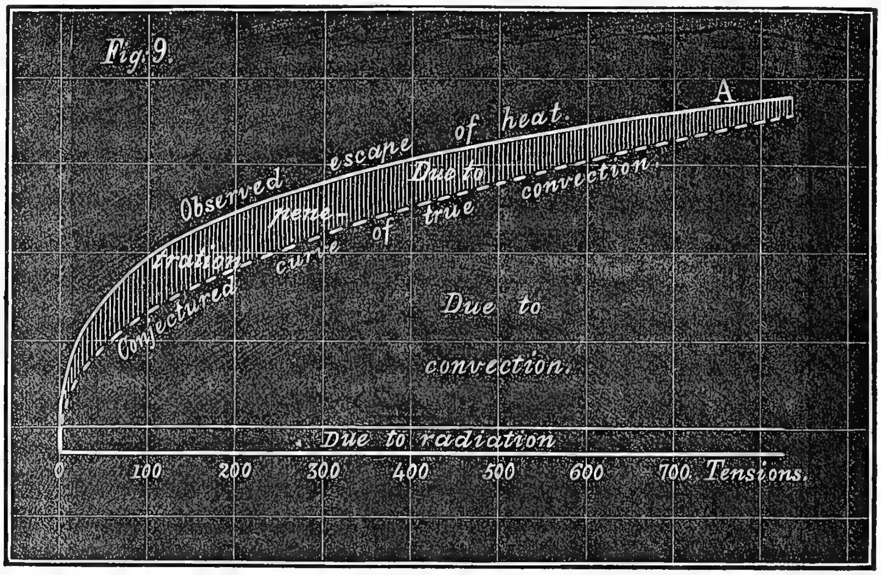
Tensions, . .	760 mm.	477 mm.	57 mm.	20 mm.	4·4 mm.
Times of cooling, .	m. s. 12 46	m. s. 13 20	m. s. 13 40	m. s. 14 49	m. s. 27 24

The rates of cooling will be as the reciprocals of these times, *i.e.*, as the numbers 652, 625, 610, 562, and 304, respectively, and to these numbers the corresponding ordinates of the upper line in our figure have been made proportional.

16. The observations previously made by Dulong and Petit on the rate of cooling in hydrogen come here to our aid. The interval between the walls of their receiver and the bulb was about $13\frac{1}{2}$ cm., and they found that, after allowing for radiation, the rest of the escape of heat within this receiver charged with hydrogen was proportional to $p^{0\cdot38}$, whereas in the other gases examined it was proportional to p in a power which differed slightly from one gas to another, but was in none far from $\frac{1}{2}$. The escape of heat with which they were here dealing, Dulong and Petit supposed to be wholly due to convection, but we have now reason to suppose that, when the gas was hydrogen, penetration contributed largely to it, and is the reason why the index of p in Dulong and Petit's empirical formula was so different with hydrogen from its value with other gases. Accordingly, if we plot down the curve—

$$y=kp^{0\cdot38},$$

in the upper line of fig. 9, to represent the observed excess of the escape of heat,



over what was accounted for by radiation, we may draw the dotted parabola crossing it somewhere to the right of A, and conclude that the convection, if it could be separated from penetration, would be represented by the ordinates of such a curve, and that the shaded interval between the two curves is due to heat having leaked away by penetration, across even so much as $13\frac{1}{2}$ cm. of hydrogen. Although we cannot assign the exact position of the dotted line until observations shall have been made in larger receivers, we can already see the general shape of the shaded space, which is at present the object of our search.

17. In a mixture of air and hydrogen within the cylinder, De la Provostaye and Desains found that at a tension of 60 mm. the rate of cooling was "*much* less" than if the hydrogen alone had been present. From this, and from the observations plotted down in fig. 8, it follows that the Crookes's layer in such a mixture is narrower than if all the molecules present had been hydrogen. This accords with

the theoretical consideration that the members of the swift procession of molecules of hydrogen will be more diverted from their course if some of the molecules they encounter are the heavier molecules of other gases.

18. Several phenomena observed by Grove, Tyndal, Magnus, and others, have been attributed to copious conduction of heat through hydrogen. May we not with more probability refer them to the very remarkable power which hydrogen possesses of allowing heat to leak away by penetration? From the dynamical theory of gases it seems improbable that any gas can possess true conducting power in a high degree, and every observer must have been struck by the violence of the first chilling effect in some of these experiments, and the unflagging energy with which it is maintained, a promptness and persistence characteristic of penetration, but quite unlike the moderate initial effect and diminished subsequent progress which we should expect from conduction.

19.* [One of the most striking of these experiments is that by Sir William Grove which exhibits the cooling effect of hydrogen on a wire rendered incandescent by the passage of an electric current; and according to the hypothesis here presented it ought to be possible to repeat this experiment *in ordinary atmospheric air* by bringing the incandescent wire sufficiently close to a cool object. This very instructive experiment was proposed by my son, Master Gerald Stoney, and has been successfully performed by him. He first passed the wire through a glass tube drawn out sufficiently thin. The effect could then be seen, but it was evanescent because the glass became rapidly heated. No doubt if the tube had been surrounded by a water jacket, the experiment might have been made in this way satisfactorily. But he made it in an equally permanent form and with greater ease, by simply bringing the incandescent wire close to a tin can containing water, to which the heat leaked away abundantly from the wire when the intervening stratum of air was sufficiently thin. The effect is best seen when the wire is of a dull red, on account of the ease with which the eye detects the difference between dull red and darkness. It then becomes conspicuous when the interval is a millimetre, and can be perceived when the interval is considerably more. In this experiment the can was at a slightly higher temperature than the room. On this account, and because a small part of the radiated heat was reflected back on the wire by the tin, the loss of heat by radiation was less than when the can was away. Moreover, the convection current was enfeebled by being both cooled and obstructed by the neighbouring obstacle. Hence the true loss of heat by penetration must have been in excess of that which manifested itself.]

20. Another phenomenon which admits of explanation by the theory developed here and in my former papers is one which is said to have caused the bursting of steam boilers, which is familiar to us as the way in which a laundress tests the

* Section 19 was re-written June 12, 1877.

heat of her smoothing-iron, and which was studied by M. Bontigny under the name of the spheroidal state of liquids. If a drop of water or other cold volatile liquid is allowed to fall into a smooth and sufficiently hot metal dish, it continues liquid instead of flashing off into vapour, and exhibits an appearance of great mobility. Here the liquid settles down upon the Crookes's layer which envelops the metal, and reduces that portion which is under it to the condition of a compressed Crookes's layer. Now the mechanical peculiarity of a compressed Crookes's layer is that it exerts more force in the direction along which the heat travels (in the present instance up and down) than in the perpendicular direction; and inasmuch as the pressure sideways *must* continue to be the pressure of the atmosphere, the excess of pressure upwards is able to support a weight. When we also remember that this excess of pressure would be augmented by still further curtailing the Crookes's layer, *i.e.*, by depressing any part of the drop, we have all the mechanical conditions necessary for the *stable* equilibrium of the drop, if only the force rises to a sufficient amount before the drop settles down quite through the Crookes's layer. This, by the theory, depends altogether on the difference of temperatures which can be maintained. The first thermal effect is that the drop becomes warmed by the radiation and penetration of heat from the hot metal below. This causes the liquid, if volatile, to lose heat by evaporation, and, in most cases, to lose a little heat also by radiation to surrounding bodies. As the temperature of the drop rises, the heat thus lost increases, while at the same time the heat received from below diminishes, and if a balance between the two is effected before the liquid reaches the boiling point, the drop continues liquid, the temperature remains henceforth unchanged, and we have before us the striking spectacle of a liquid in the spheroidal state.

Addition made June 24, 1877.

21. I have long thought it likely that the drops which may be sometimes seen running over the surface of a volatile liquid rest upon compressed Crookes's layers intervening between them and the liquid on which they float: that they are, in fact, drops in the spheroidal state. Some recent observations abundantly confirm this suspicion. These floating globules are easily formed when a liquid as volatile as spirits of wine is allowed to fall in drops of a medium size from a height of about 8 centimetres into a vessel containing some of the same liquid moderately warmed. They can also be occasionally produced by dropping the spirits of wine upon water. And everyone is familiar with them when, in some states of the weather, they roll about in numbers on allowing water to drip from an oar upon the sea. Yesterday they were abundantly produced by splashing the water of a neighbouring pond, and I took advantage of the opportunity to ascertain that the conditions required by the hypothesis were fulfilled. The temperature of the air was about 15°, that of the surface of the water 18° and a quarter, and a very dry

breeze was blowing, which so facilitated evaporation from the drops* that they probably maintained a temperature as low as 10°, a temperature which my thermometer reached when I left a damp weed in contact with one side of the bulb.

When the globules of methylated spirit were formed upon a beaker nearly full of the same liquid, which was progressively warmed, it was found that, when the air was still, there was a particular temperature at which the drops were most persistent. At this temperature some lasted for as long as twelve or fourteen seconds. As the temperature rose beyond this point, the atmosphere of vapour impeded evaporation and the persistence of the drops became less; but by gently blowing on the surface so as to accelerate the evaporation, it was found possible to keep some of them in existence for two or three minutes,† during which time they very slowly dwindled away till they were quite small, and then suddenly vanished. When the temperature of the beaker full of spirit was allowed to fall below the point above referred to, the duration of the drops also became progressively less; but they could still be formed, though short-lived, at a temperature a little below that of the room.

From this, and from the circumstance that I succeeded in forming some within a bottle of methylated spirit which had been standing open for a while, and within which evaporation must have been feeble, it is evident that a drop can be supported with but a slight difference of temperature between it and the liquid on which it rests. In this respect the spheroidal state on liquids differs from that in which the drop rests upon a heated solid. The difference of behaviour is probably due to the deformation of its natural spherical shape to which a drop is compelled to submit when it rests on a rigid surface. Owing to this constraint the surface-tension over the drop will force some parts into closer contact, and, moreover, the vibrations which always arise in this case must tend to a similar result. On the other hand, when the drop is resting on a liquid, it settles tranquilly into a beautiful concave socket that can be seen by looking at the surface of the fluid from beneath. This socket allows the globule to retain a nearly spherical and therefore unconstrained form, and, accordingly, the opposed surfaces come within an approximately equal distance of one another throughout a large arc. And it is evident that as the whole pressure arising from the molecular motions in the air would support a column of spirits of wine $11\frac{1}{2}$ metres high, it needs only a very moderate Crookes's procession across the stratum of air to furnish that slight preponderance of

* The liquid on which the drops rest is no doubt also cooled by evaporation, but in a trifling degree, because convection currents constantly bring to the surface an accession of warm liquid from below.

† In three better arranged experiments, since made in the laboratory of the Society by Mr. Moss and myself, and of which we hope to give an account to the Society, we succeeded in maintaining similar drops formed on ether for ten, fourteen, and sixteen minutes, respectively; and we believe that it will not be difficult, by securing a greater constancy in the conditions indicated by the theory, to prolong their existence very much more.

velocities in a determinate direction, which is required to support the few additional millimetres that correspond to the weight of the drop. We must remember, too, that a drop may, under favourable circumstances, outlive the difference of temperature, because it would take a sensible time for so slight a pressure as the weight of the drop to squeeze the film of air, when once established, out of its narrow chink. Even a heavy metal proof-plane will float over another proof-plane upon the stratum of air entangled between them, for a considerable time.

22. Professor Barrett has called my attention to another unexplained phenomenon, of which we can now see the cause, viz., the mobility imparted to a very fine powder, as, for example, magnesium carbonate or precipitated silica, by heating it in a metal dish. When the dish is disturbed the powder glides about as if floating; and it is in fact floating on the compressed Crookes's layer, which will spring into existence whenever the powder is able by radiation to maintain a lower temperature than the dish.

23. The communication of heat by penetration is a very familiar phenomenon, for when surfaces at different temperatures are brought into what is commonly called contact, there is usually a thin intervening stratum of air, except at special points; and, accordingly, the greater part of the transfer of heat, so long as the difference of temperature is considerable, must be effected, not by contact, but by penetration across a Crookes's layer.

Note to Section 8.—De la Provostaye and Desains conclude their second memoir in the following words:—" Nous ne chercherons à donner une explication complète des différents faits cités dans cette communication. Nous ferons remarquer seulement que le pouvoir refroidissant d'un gaz dépend de sa densité et de sa mobilité. Ces deux éléments varient en sens inverse quand on change la pression, et l'on conçoit que les effets de ces variations contraires puissent tantôt s'équilibrer, tantôt se surpasser dans un sens ou dans l'autre."

Note to Sections 10, 12, and 15.—An account of De la Provostaye and Desains' experiments is given also in the *Annales de Chimie*, Third Series, Vol. xvi., p. 381, and Vol. xxii., p. 362. This account does not differ much from the report in the *Comptes Rendus*, but contains one important addition, viz.—a statement of the size and shape of the thermometer bulb. It was a cylinder 7 cm. long and 2 cm. across; so that the interval between the bulb and the wall of the smallest receiver was 2 cm. The reader is accordingly requested to substitute 2 cm. for $1\frac{1}{2}$ cm. in Sections 10, 12, and 15.

[*MAY, 1878.*]

THE

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ON THE SATELLITES OF MARS.

BY

WENTWORTH ERCK, LL.D., F.R.A.S.,

[READ BEFORE THE SOCIETY, NOVEMBER 19TH, 1877.]

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1878.

ON THE SATELLITES OF MARS.

BY

WENTWORTH ERCK, LL.D., F.R.A.S.

[Read 19th November, 1877.]

On the 19th of August the astronomical world was startled by the receipt of a telegram from Washington announcing the discovery of two satellites to the planet Mars.

There was some ground for the incredulity that was at first expressed, for it seemed hardly credible that the satellites of our nearest celestial neighbour should have been overlooked whilst those of the most distant planets had been long since discovered.

But, when it is considered how many circumstances must combine to render these exceedingly minute bodies visible, we shall cease to wonder at their not having been discovered earlier.

Chief among the conditions of visibility are, (1) the position of the planet with regard to our earth, and (2) the possession of telescopes of exquisite defining power.

1. As to the first condition; it is only at opposition that there is any possibility of observing Mars to advantage, and the eccentricity of his orbit being considerable, it is only at those oppositions which occur when the planet is in perihelion that he can be seen to the best advantage.

Taking our own distance from the Sun as unity, the perihelion opposition distance of Mars from us is only 0.38, while his aphelion opposition distance from us is 0.66, or nearly twice as great. But, unfortunately, these perihelion oppositions are rare, owing to the relative periodic times of the Earth and Mars.

In 1798 there was an opposition very near to perihelion. During the present century the oppositions, reckoned according to their proximity to perihelion, are those of 1845, 1877, 1830, 1892, 1862, 1860, 1847, 1849.

The opposition of 1845 was the nearest to perihelion, occurring about ten days prior to it, whilst that of 1877, the next nearest, was fourteen days after perihelion. But, though at the opposition of 1845 the Earth was nearer to the planet than at any other time during the century, yet at that opposition the planet, as seen from this latitude, was too low in the heavens for successful observation.

At the opposition of 1830 he was pretty high in the heavens, but further off, whereas at the opposition which has just taken place, his altitude, as seen from our latitude, was about 28° when on the meridian, and his distance was very little greater than in 1845, so that on the whole the recent opposition was probably the most

favourable for observation during the present century. But even at this most favourable opposition, the period of time during which the planet was sufficiently near to us to admit of his satellites being seen, did not exceed a couple of months. Again, it must be remembered, that it is only at, or near to, the time of greatest elongation from the primary that the satellites can be seen—even with the Washington telescope they were only visible when within 30° of greatest elongation; or, in other words, only during one third part of their orbits.

2. Regarding the other condition of visibility, the possession of telescopes of exquisite defining power, it must be borne in mind that the earliest telescopes at all capable of dealing with such objects as the satellites of Mars were the reflectors of Sir William Herschel wherewith the satellites of Uranus and the inner satellites of Saturn were discovered.

Sir Wm. and Sir John Herschel have left on record several thousand observations of what they saw, but judging from what they failed to see, *e.g.*, the companions of Sirius and Antares, and the Sixth Star in the trapezium, we may pretty safely say that no telescope of theirs would have shown the satellites of Mars.

Next, having regard to reflecting telescopes, we come to those of Lord Rosse, which were constructed chiefly with a view to the examination of the Nebulæ, and in these telescopes perfection of definition seems to have been in some degree sacrificed to the collection of an immense quantity of light—such telescopes are not adapted to show the satellites of Mars. Then comes the two feet reflector, constructed by Mr. Lassell in 1846, with which were discovered the Hyperion satellite of Saturn, the satellite of Neptune, and the two innermost satellites of Uranus; and this, I believe, to have been the first reflecting telescope capable of showing the satellites of Mars.

Another telescope of four feet in diameter, constructed by Mr. Lassell in 1860, is no longer in existence; and the four feet reflector at Melbourne, was unfortunately disabled at the time of the late opposition.

Lastly, we come to the modern silver-on-glass reflectors, introduced by Foucault; several of these are undoubtedly capable of showing the satellites of Mars, indeed the only European measures of the outer satellite that I know of, besides my own, were made with an eighteen-inch silver-on-glass, by Calver, of Chelmsford, the focal length of which is only five times the diameter.

Turning our attention next to refracting telescopes, we find that the first refractors at all capable of dealing with such objects as the Satellites of Mars, were those of Fraunhofer, *circa* 1827. Of these the most famous was that at Dorpat, 9.5 inches in diameter, employed by the elder Struvè in the construction of his great catalogue of double stars. This telescope has, probably, done more recorded work than any other.

Next in point of date come three great object-glasses, of about 12 inches in diameter, by Cauchoix of Paris, *inter* 1827 and 1830. These excited great attention

in their day. One of them was presented by the then Duke of Northumberland to Cambridge Observatory, where it still is. Another was purchased by the late Mr. Edward Cooper, of Markree Castle, in the county of Sligo, where it still remains. The third, and best of the three, became the property of the late Sir James South, by whom it was presented to Trinity College, Dublin, in whose observatory at Dunsink it now is.

None of these telescopes, however, were up to the required mark.

From the death of Fraunhofer in 1830 till, perhaps, 1845, the only maker of repute was Mertz, of Munich, who constructed nearly all the great telescopes within these dates. Some of his object-glasses reached a diameter of even 15 inches.

But about the latter date two other eminent makers of telescopes appeared, viz., Cooke, of York, and Alvan Clarke, of Boston, U.S., who have produced the finest and the largest telescopes yet constructed. The former having completed, in 1873, the great refractor, at Gateshead, in the County of Durham, 25 inches in diameter; and the latter having, very shortly afterwards, produced the great Washington refractor, 26 inches in diameter. This refractor, regard being had to both its quality and its size, is undoubtedly the finest in existence, but it will not long enjoy this pre-eminence, as we hope it will soon be equalled in quality and exceeded in size by the Vienna refractor, of 27 inches aperture, now in course of construction by Mr. Grubb, of Dublin, who, during the last few years has supplied most of the great telescopes, both reflectors and refractors, in Europe, America, and Australia.

Thus it appears that prior to 1846 there were no telescopes capable of showing the satellites; and since 1846 there have been no oppositions of Mars nearly so favourable for viewing the satellites as the recent one, so that we may say, with almost certainty, it was impossible they could have been discovered earlier than they have been.

Detailed elements of the satellites having appeared in several of the scientific papers, it is unnecessary to repeat them here; but there is one circumstance connected with the inner satellite which is deserving of notice as it is entirely without precedent in the Solar System—it is this: that the angular motion of the satellite in its orbit is more than three times as rapid as that of its primary round his axis, that is to say, while Mars rotates once the satellite completes three and a quarter revolutions round him. There is no other known instance in which a satellite completes its orbital revolution in less time than the primary completes a revolution on his axis.

The next swiftest moving satellite, in reference to the rotation of its primary, is satellite I of Saturn, which completes a revolution in orbit in 2.2 rotations of Saturn himself.

I shall now proceed to my own observations of the outer satellite. On the 2nd September I, for the first time, looked for it, and at once perceived

a faint object at about 290°, and distant from the limb rather more than two diameters of the planet. During the short time I was able to observe it, the direction of the motion resembled that of a satellite moving in the direction in which the motion of a double star is reckoned.

It subsequently appeared that I was mistaken in supposing this to have been the satellite; but yet the observation of this star has proved most valuable; for, its position with regard to the planet was similar to that in which the true satellite was afterwards seen, whilst its apparent brightness was, as nearly as I could judge, the same as that of the satellite itself. Thus, when the star was left behind, by the motion of the planet, we had an isolated standard of comparison whereby to estimate the brightness of the satellite irrespective of the light of its primary. The telescope I employed was a $7\frac{1}{2}$-inch by Alvan Clarke, and it is a curious coincidence, that the telescope with which the satellites were discovered in America, and that with which the outer satellite was first seen in the United Kingdom, were both by the same maker. Contrary to my expectation, there was no difficulty in seeing the satellite when proper precautions were taken. I used an hexagonal aperture on the object glass, and, as an eye piece, a single lens giving a power of 300. The field of view was limited to two minutes of arc, and the planet itself placed just outside the field. I then turned the hexagonal aperture till the satellite was exactly in the centre of the angle formed by the rays; when this was done it only remained to read off by the position circle the position of the rays, and adding 30°, there was the position of the satellite. But the estimate of distance was little more than guess-work, the standard of estimation not being in sight along with the distance to be estimated.

On every occasion I looked for the inner satellite, but looked in vain; indeed, so far as I have been able to ascertain, the inner satellite has not been seen in Europe.

But, one word with regard to the use of large apertures in such cases. They seem to me to be nearly useless, as in practice they are found to illuminate the back ground against which the faint object is seen. Of course, if the figure and material of the object-glass were perfect, or even as good as some of the small ones, and if it could be relieved from the strain produced by its own weight, then the gain would be great; but, so far as my experience and information go, such is not the case.

As an instance, of the very small aperture with which the satellite could be seen, I may mention that I had little difficulty in seeing it steadily, not by glimpses, with an equilateral triangular aperture, whose side was 6 inches, giving an area of $16\frac{1}{2}$ inches, equivalent to a circular aperture of $4\frac{1}{2}$ inches diameter, and I am quite confident that it could have been seen with a yet smaller aperture. Still, though this aperture may appear small to have shown the satellite, *in loco*, it is perfectly certain, judging from the comparison hereafter to be mentioned, that less than *one-third* of this aperture, that is to say, less than one-tenth of the area would

have sufficed to have shown the satellite if it could have been removed away from the overpowering splendour of the planet itself; so that, notwithstanding all our precautions to exclude the light of the planet, fully nine-tenths of the light of the satellite were overwhelmed thereby, and without the precautions adopted the satellite would have been utterly invisible.

My observations of the satellite were as follows, and at the time of making them I had no knowledge whatever of its place; indeed, the first Ephemeris published was that in *Nature,* of the 13th September, previous to seeing which I had communicated my observations of the 4th, 8th, and 15th.

The times are Greenwich sidereal :—

—	Epoch, 1877.			Position.	Observations.
September, .	3	23	0	64°	Distance from limb, perhaps 3 diameters.
,, .	4	0	0	–	Distance now estimated at 2 diameters.
,, .	4	1	0	55°	
,, .	8	22	35	78	Cloudy.
,, .	15	21	10	257	
,, .	,,	23	30	243	Watched the motion during interval.
,, .	16	1	–	238	
,, .	25	21	20	270	Gibbosity conspicuous; Satellite very much fainter than formerly.
,, .	,,	22	20	264°	Sufficient moonlight to read Nautical Almanack.
,, .	26	0	35	255°	
,, .	27	23	0	69°	Mean of 2 measures; distance perhaps 3 diameters. It is exceedingly faint; I can scarcely see it.
October, .	2	24	–	70°	I think, but only think, I see the Satellite about this position; however, on referring to the Ephemeris, I find that such was its place at that time.

This was the last time I saw the satellite, though I looked for it under favourable circumstances on the 4th, 8th, and 11th October.

At transit on the 27th September, when the satellite had become all but invisible to me, the log. distance of the planet was 9.625; and the log. radius vector, was 0.143, so that the brilliancy of the planet at this time was but 0.82 of his brilliancy on 5th September, the day of opposition.

Of all the oppositions since 1849 the only one at which the brilliancy exceeded 0.82 was that of 1860, when the brilliancy on 20th July was 0.93; but the twilight at that season of the year would probably have extinguished the satellite. Similar considerations will probably suffice to show how easily the satellite may have escaped detection in former years.

It does not appear probable that the satellite varies very much in brightness, for it was as well seen in the preceding as in the following half of its orbit; in the former from 238° to 270°; in the latter from 55° to 78°.

As to the size of this satellite, seeing that it does not present any sensible disc (indeed, the actual disc cannot be a tenth of a second), it only remains

for us to guess at the size from the brightness, on the assumption that the surface of the satellite is of equal reflecting power with that of the planet itself. The comparison can, of course, only be effected, by means of an intermediate object seen under precisely similar circumstances, with regard to the planet, as the satellite itself.

Such objects were the stars A and B.* A is the star which on 2nd September was mistaken for the satellite; its position then, with regard to the planet, was about 290°; and distance from the limb about three diameters of the planet. Subsequent observations caused me to estimate the star A as slightly fainter than the satellite.

Again, on 15th September, at 23 hours G. S. T., the star B was seen; its position then was about 280°; and distance from limb of planet *circa*, 90″. This star was fortunately seen in the field *along with* the satellite itself, and was judged to be a little fainter than the satellite. The comparison was made, two or three times, at short intervals. So I concluded that the satellite was decidedly brighter than A, and very slightly brighter than B. The next thing was to determine the brightness of A and B by means of extinguishing apertures.

After several experiments, on different nights, I found that the mean limiting aperture for A was 2.0 inches; and for B 1.5 inches. By limiting aperture I mean the aperture just sufficient to show the star distinctly. But as the satellite was slightly brighter than B I shall assume the limiting aperture for the satellite to have been 1.4 inches.

Now 1.4 inches aperture, with my eye and telescope, corresponds to 9.5 mag. Struvè, or 13 mag. h., and such therefore I estimate the satellite to have been on the 15th September.

Having thus ascertained the limiting aperture for the satellite, I next tried to obtain the limiting apertures for Mars himself, and also for Vesta, which was in the immediate neighbourhood.

In the case of Mars, seen through an exceedingly small aperture, I found, as might have been expected, that magnifying power was not admissible, for it converted the enlarged disc into a nebulous haze. In the case of Mars,

* The places of A and B are:—

A : RA=23 12 0; PD=101 57 50.
B : RA=22 58 0; PD=102 42 0.

The above places are not corrected for refraction, and may be in error to the extent of 5 seconds of time and 30 seconds of arc.

The star A is 10 magnitude Struvè, or 14 mag. h.; it is preceded on the parallel, at 10 seconds, by another star of the same magnitude. There is an 8.5 Struvè preceding A, at about 67 seconds, and 1 minute true north of it.

The star B is the larger component of a double star; mags. 9.6 and 10 Struvè; distance *circa*, 70″, and position angle, 350°. This is the true northern, and faintest, of two or three somewhat similar doubles in a field of perhaps half a degree.

therefore, I employed the naked eye only, and, not having an aperture small enough to extinguish *him,* I estimated his limiting aperture from that of α Lyræ, which I found to be 0.01 inch.

Now, on the 15th September I estimated Mars seen through an aperture of 0.01 inches to be fully a Struvèan magnitude greater than α Lyræ seen through the same aperture; and therefore the limiting aperture for Mars would have been 0.005 inch.

But the aperture for the satellite was 1.40 inches; now these apertures are to each other, inversely, as 1,000 to 3.6.

This ratio of aperture was further confirmed by viewing the planet and the star B through neutral tint coloured sun glasses, which admitted the use of the telescope and larger apertures; it was also confirmed by viewing both objects reflected from the first surface of a prism, as is done when looking at the sun.

Now, assuming the reflecting powers of the planet and the satellite to be similar, their diameters will be inversely as their limiting apertures, that is as 1,000 to 3.6; so that if we take the diameter of Mars as 4,000 miles, we have as the diameter of the satellite $3.6 \times 4 = 14$ miles; or, at the then distance of Mars, the disc of the satellite would subtend an angle of about 0.08 seconds.

In the case of Vesta, as with the satellites of Saturn, I found that, owing to the exceeding minuteness of the discs, there was very little loss of light in using a magnifying power of 300, which had been employed on the satellite of Mars. With this power I found the limiting aperture for Vesta to be 0.25 inch; but if Vesta, on 8th of October, the day of comparison, had been in the place of Mars on the 15th September, her light would have been increased 45 times; and therefore her limiting aperture would have been reduced from 0.25 inch to 0.037 inch.

Thus the apertures for Vesta, seen under the same circumstances as the Satellite of Mars, and for the Satellite, are 0.037 and 1.4 inches, or very nearly in the ratio of 1 to 40; so that if Vesta reflects light as does the Satellite, then the diameter of the Satellite would be $\frac{1}{40}$th of the diameter of Vesta.

Now, according to the best authorities, the diameter of Vesta is supposed to be 230 miles, which, at present distance, would correspond to a disc of 0.7 seconds, and this cannot be far from the size of the actual disc visible in the telescope.

Taking the diameter as 240 miles we have as the diameter of the Satellite, on the assumption of equal reflection, 6 miles. It is a very curious coincidence that the mean of these two values, 14 and 6, is exactly the estimated diameter given by Professor Hall, viz. 10 miles; and also how this value, 6 miles, obtained on the assumption of equal reflection with Vesta, agrees with Mr. Procter's estimate of 5 miles.

But I think it will appear that the reflecting power of Mars, or his satellites, and that of Vesta are *by no means* equal. For if, on the 18th September, Mars had

been removed to the distance of Vesta, his light would have been enfeebled 40 times; and therefore his limiting aperture would require to be increased to $\sqrt{40}$, or 6.4 times, and so would have become 0.032 inches.

But the limiting aperture for Vesta is 0.25 inches, or only 8 times that of Mars at her distance.

Therefore, on the assumption of equal reflecting powers, the diameter of Vesta should be an eighth of that of Mars, or 520 miles; but it is highly improbable that her diameter is more than half that quantity, and therefore her reflecting power must be more than 4 times that of Mars; and if we assume the received value of the diameter of Vesta, 230 miles, to be correct, then it will appear that her reflecting power is 5.2 times that of Mars, whose diameter is 4150 miles; for $(230\times 8)^2\times 5.2=4150^2$.

Now applying this correction to the diameter of the Satellite, as determined by comparison with Vesta, we must increase the area of the disc of the Satellite 5.2 times, or multiply the diameter by $\sqrt{5.2}$ which is 2.2; but $6\times 2.2=13.2$, so that comparison with Vesta gives the diameter of the Satellite as 13.2 miles.

Great as the disparity between the reflecting powers of Mars and Vesta may thus appear to be, still it is corroborated by other observations.

In the first place, Vesta is known to be the brightest of the minor planets (Chambers); that is to say, her light is more intense than that of any other.

In the next place, the light of Mars is well known to be less intense than that of Jupiter or Saturn; and for the purpose of getting some idea of the relative reflecting power of the surfaces of these planets, I endeavoured to compare their *actual* apparent brightness with their calculated brightness on the assumption of equal reflection.

On several occasions, about the 5th of this month, I measured, as carefully as my means would admit, the relative brightness of Mars, Jupiter, and Saturn. I noted the time at which the two former became visible in the twilight at nearly equal altitudes; also, I employed the neutral tint sun glasses with limiting apertures, and also reflexion from the first surface of a prism. After many trials I came to the conclusion that Mars and Jupiter were, as nearly as I could judge, of equal brightness, and 10 times as bright as Saturn.

Of course it is necessary to make some allowance for the superior illumination of the western sky wherein Jupiter was. Suppose we assume this to have reduced his brightness one-tenth, the comparison of actual apparent brightness would then stand nearly thus—

Jupiter 100 : Mars 90 : Saturn 9.

It is easy to calculate the amount of light received by us from any planet at any distance—

The light is equal to $\frac{\Delta^2}{D^2\times V^2}\times N$ where—

Δ=Diameter of planet.
D=Distance from us.
V=Radius vector, or distance from Sun.
N=Comparative reflecting power of surface.

Calculated according to this formula, and assuming equal reflection, the apparent brightness would have been on 5th Nov., Jupiter 100; Mars 260; Saturn 8.6, and Vesta 0.034, whereas the actual brightness was—Jupiter 100; Mars 90; Saturn 9, and Vesta 0.040.

These figures evidently agree as well as could be expected, except in the case of Mars, whose light ought to have been three times as great as it was; whence we infer that his surface reflects only one-third of the light reflected by the other planets, and thus the foregoing direct comparison with Vesta receives additional confirmation.

So then the diameter of the Satellite, obtained from direct comparison with Mars is 14 miles: from comparison with Vesta 13.2 miles, giving a mean diameter of 13.6 miles, or $\frac{1}{300}$th part of that of Mars himself, corresponding to a disc, at the mean distance of Mars, of about $\frac{1}{30}$th of a second arc.

If the diameter of the satellite be $\frac{1}{300}$th, its volume will be $\frac{1}{27,000,000}$, and the mass probably about $\frac{1}{40,000,000}$ of that of Mars.

Two such satellites as these, at the respective distances of 2.7 and 6.8 radii, would be utterly powerless to produce any sensible tidal action on the seas of Mars.

The preceding observations refer to the outer satellite; the inner one has been repeatedly observed in America, viz., at Harvard College and at Glasgow, Missouri, as well as at Washington; but it has not been seen, with certainty, so far as I know, in Europe.

The planets of our system, commencing with the Earth are now shown to be accompanied by satellites whose numbers are in geometrical progression: thus, the Earth has 1, Mars has 2, Jupiter has 4, Saturn has 8, Uranus has, at least 4, and probably a greater number, while the exceeding great distance of Neptune prevents us from recognising more than one of his.

Probably it was the single step wanting in this progression which suggested to Swift and Voltaire their guesses as to satellites whose existence has now, for the first time, been ascertained.

[illegible]

[October, 1878.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

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IV.—*On the Mechanical Theory of Crookes's, or Polarization Stress in Gases.* By G. Johnstone Stoney, M.A., F.R.S., &c., Secretary to the Society. [Read February 18th, 1878.]

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IV.—ON THE MECHANICAL THEORY OF CROOKES'S, OR POLARIZATION, STRESS IN GASES.

BY

G. JOHNSTONE STONEY, M.A., F.R.S., &c.,

Secretary to the Society.

[Read February 18, 1878.]

Introduction.

Two papers will be found in the first volume of the fifth series of the Philosophical Magazine (March and April, 1876), in which I endeavoured to explain the force that Mr. Crookes had detected within vacuum chambers, by pointing out that when heat passes across the residual gas, the molecules of the gas that tend respectively towards the heater and towards the cooler must interpenetrate one another in a greater degree than they would if the gas were in its ordinary or unpolarized condition, and that this behaviour will render the stresses within the gas unequal, causing the stress to be greatest in the direction in which the augmented interpenetration takes place.

When writing the foregoing papers, and afterwards when writing a paper on the transfer of heat which accompanies the phenomenon, I was under the mistaken impression that the flow of heat between a heater and cooler in fixed positions and at constant temperatures, will become greater if the number of gaseous molecules that intervene is reduced below the number required for the transfer of heat by the laws of "conduction*"; and for this supposed increased flow of heat I suggested the name penetration. It has recently been pointed out by Dr. Schuster, "Nature," vol. 17, p. 143, that experiments have been made which show that the flow of heat diminishes instead of increasing when the limit for "conduction" is passed. It thus appears that what I have called penetration is always feebler than conduction, and is to be sought in the figures representing De la Provostaye and Desains' experiments in those portions of the curves which slope steeply downwards. Accordingly my paper on penetration (Memoir 2 of the present volume), and especially that part of it in which I apply the theory to experiment, requires considerable modification, and some of the statements I made in my earlier papers on Crookes's force need amendment. Although the corrections that are required do not affect any material part of the theory of unequal stresses within polarized gas, it has appeared desirable

* It is known that gases feebly conduct heat by diffusion, and that the amount of heat which passes in this way between a heater and cooler is independent of the density of the intervening gas, provided that the density of the gas does not fall below a certain limit. The question that presented itself was, as to what happens below that limit.

to resume the subject and present the theory freed from the error that has been pointed out. In doing this I have taken the opportunity of introducing the conception of the *reflecting tube*, which greatly facilitates the inquiry into the mechanical effect of the interpenetration; and I have also availed myself of the admirable method of treating the problem described by Mr. George F. Fitzgerald in "Nature," vol. 17, p. 200, to obtain a complete expression for the stress, and to show that my theory is not at variance with results established by Professor Clausius, as had been asserted by Professor Osborne Reynolds in "Nature," vol. 17, p. 122.

PART I.—TREATMENT OF THE PROBLEM BY GENERAL MECHANICAL CONSIDERATIONS.

1. If a drop of water or other volatile liquid is allowed to fall into a smooth and sufficiently hot metal dish, it continues a liquid drop instead of spreading out or flashing off into vapour, and it exhibits an appearence of great mobility. The drop is then in what has been called the "Spheroidal state." Now when a drop of liquid is so situated, a chink may be observed between it and the hot surface beneath; so that the drop does not rest directly upon the metal, but is in reality floating upon a layer of vapour. We further learn from these observations that after the brief interval of adjustment is over the layer of vapour presses upwards and downwards more than it presses sideways; for the pressure sideways must *equal* the pressure of the atmosphere so soon as the adjustment is over, otherwise air would still be entering or leaving the chink, whereas the pressure upwards must *exceed* the pressure of the atmosphere by an amount able to support the drop. It is my object to explain how this difference of pressures, this Crookes's pressure as it has been called, comes into existence.

2. The thermal conditions of the problem are easily traced, but need not detain us here. It is enough to state that they show the metal dish and drop to be at different temperatures, so that they are a heater and cooler on either side of the layer of vapour. Experiment further shows that the heater and cooler may be either one a liquid and one a solid, as in the case already considered, or both liquids, or both solid, and that the intervening layer may be either vapour or permanent gas. This last important fact has been established by Mr. Richard Moss in an admirable series of experiments lately made by him to test the theory of the present communication (see Scientific Proceedings of the Royal Dublin Society, vol. 1. p. 89). It is also found to be immaterial whether the heater or cooler is uppermost, or whether they face one another sideways.

Other facts of importance have been elicited by the experiments at low tensions: of which the most significant are that when the heater and cooler are maintained at given temperatures the Crookes's stress between them may be increased either by bringing the heater and cooler closer together, or by attenuating the gas until a certain point is reached which varies from one gas to another; and that when that point is passed the force decreases and apparently without limit.

3. We may express these facts in a very convenient form for our present purpose if the heater and cooler are extensive flat parallel surfaces at fixed temperatures. Conceive two exactly similar patches on the heater and cooler directly opposite to each other, and each occupying a unit of surface, and consider that portion of space which lies between these. Then the observations show that there is one definite quantity of the gas to be left in the volume so marked out, if we wish to produce the strongest Crookes's stress. And further, by comparing Mr. Crookes's experiments on the mechanical action, with those of De la Provostaye and Desains on the flow of heat, we learn another important fact, viz.: that the maximum stress occurs when the quantity of gas is too little to admit of the passage of heat under the laws of the conduction of heat in gases. Now these facts also follow as consequences from the theory advanced by the author, and therefore become confirmations of it.

4. This theory seeks to account for Crookes's force by showing that a layer of gas placed between a heater and cooler is in a polarized condition of such a kind that the stresses within the gas are different in different directions. Gas is polarized whenever the molecules within a spherical element of volume are moving towards different quarters with numbers or velocities that are not distributed alike in all directions, the velocites being measured from the centre of mass of these molecules. This definition excludes the case of mere wind, which is to be regarded as unpolarized gas travelling forward in a certain direction, but it includes the case of gas across which heat is making its way, which is the case with which we have here to deal.

5. Let us recur to the simple instance of a heater and cooler with extensive flat parallel surfaces maintained at constant temperatures, and with gas between them freed from the action of gravity and which has had time to adjust itself to its position. Gas so circumstanced will become stationary in the ordinary sense of the word, *i.e.*, though in active molecular motion, it will have no currents like convection currents or wind passing through it.* We have now to show that the stress across such a layer will be greater than the stress sideways.

6. Imagine a unit of surface marked out on either heater or cooler and let perpendiculars to the surface be raised from the boundary of this enclosure. These will trace out a straight tube extending between the heater and cooler, and closed at the ends by equal patches of the heater and cooler. These we may call the pistons of the tube. The molecules which strike the pistons are returned by them, and with altered velocity whenever the pistons are at different temperatures; but molecules pass without hindrance through the sides of the tube. Now it is evident that if the molecules passing through an element of the side of the tube are considered, those passing out in a unit of time will be an exact counterpart of those passing

* There will be currents close to the boundary of the heater and cooler, but these are secondary phenomena caused by, and in no degree the cause of, Crookes's stress. They will not be appreciable within the layer at any considerable distance from the edge, and they may be avoided by giving to the opposite surfaces of the heater and cooler the form of concentric spheres.

in, in such a sense that the state of the gas would not be disturbed by making the sides of the tube impervious to molecules, provided they were made at the same time *perfect reflectors* of molecules. By a reflector of molecules is to be understood a surface endowed with the property of throwing off any molecules that impinge upon it, with unabated speed and at an angle of reflection which lies in the same plane as the angle of incidence and is equal to it. The reflected molecules will affect the state of the gas within the tube exactly in the same way as the molecules passing in from outside had done before. We have now a portion of gas completely shut up inside a tube with sides that are perfect reflectors of molecules, and closed at the ends by pistons that are patches of the heater and cooler and which therefore scatter such molecules as reach them; and we know that the behaviour of this gas will be the same as that of the corresponding portion of the Crookes's layer. We may call such a tube, a unit reflecting tube.

7. Let the pistons of such a tube be kept at the temperatures T_1 & T_2, and let gas be introduced into it. After a brief period of adjustment the gas will become stationary, *i.e.*, if a plane forming a cross section of the tube be considered, the molecular motions are such that the same number of molecules pass forwards as backwards through this plane per second. But they will pass it with unequal average velocities, because the vis viva of those crossing it towards the cooler must exceed the vis viva of those crossing it towards the heater, by an amount bearing a known ratio to the quantity of heat advancing. Hence the gas is polarized, the molecular motions being swifter when they are directed forward or towards the cooler and slower when directed backwards.

8. Suppose that we begin with dense gas and gradually exhaust, and let us consider the succession of events that will arise as the exhaustion proceeds, *i.e.*, when n, the number of molecules in the unit tube, is progressively diminished. It is known that the flow of heat cannot conform to the laws of "conduction" unless the number of molecules exceeds a certain limit which we may call N, N depending upon the description of gas that is present, and upon the temperatures T_1 and T_2 of the pistons which close the unit tube. We must, therefore, divide the exhaustion into two periods, one lasting while the number of molecules in the tube exceeds N, and the other during the rest of the exhaustion. Throughout the first period the flow of heat follows the known laws of conduction, and therefore remains constant. Hence, during this part of the exhaustion the polarization of the gas (which may be measured by $\frac{\delta v}{v}$, v being the average velocity at any point of the layer, and δv the average difference of the velocities forwards and backwards at that station), is so rapidly on the increase as quite to compensate in $\kappa\rho v^2\delta v$ (the expression for the flow of heat, ρ being the density at the station, and K a constant), for the diminishing density. During the second period, *i.e.*, when the molecules have become fewer than N, the polarization is still on the increase, but not so rapidly as before, and at

the same time the flow of heat decreases to zero; for while ρ tends to zero as the exhaustion proceeds, the polarization does not tend to infinity, but to a limit, viz.: $\frac{v_1 - v_2}{\sqrt{v_1 v_2}}$ where v_1 and v_2 are the velocities corresponding to T_1 and T_2, the temperatures of the pistons. Now when gas is polarized with this kind of polarization within a tube the sides of which reflect the molecules, we can find limits between which its thermal and mechanical properties must lie.

9. Before proceeding to determine these limits it will be well to guard ourselves against making mistakes by passing under review the orders of the several magnitudes with which we are dealing in this inquiry. No *accurate* measures appear yet to have been made of the thickness of the chinks of air or vapour on which spheroidal drops rest. But from approximate measures, some of which were made by Mr. Fitzgerald, and some by myself, I think it may be inferred that this thickness is somewhere about the thickness of a sheet of paper (*i.e.*, about a fourth-metre or the tenth of a millimetre), when a spheroidal drop of the density of water, at a temperature of 10° centigrade, and 4 or 6 millims in diameter, floats over a surface of liquid which is about 10° warmer. We further know in this case that the Crookes's pressure, as it supports the weight of this drop, must be about the two-thousandth part of an atmosphere. These determinations are very rude, but they at all events tell us what kind of magnitude we are dealing with, and therefore suffice for our present purpose. They show that we shall not be *far* wrong in assuming definitively that the phenomenon presented by experiment which we have to explain is that the stress across a stratum of air will be $\frac{1}{2000}$ part of the stress at right angles to that direction, if this stratum occupies the space between a heater and cooler at temperatures of 10° and 20° C, if, moreover, this interval is a fourth-metre (a metre divided by 10^4), and if the atmosphere has free access to the stratum of air at its edges. Let us now imagine a reflecting tube, such as is described above, to be placed across this stratum. It will therefore be a fourth-metre long, and we may assign to it any width we please. Let us take a width equal to the diameter of the smallest object that can be seen with a microscope, which is about 2·5 seventh-metres, or the 100,000th part of an inch. We have now to compare the dimensions of this tube with the number and motions of the molecules included within it. The number of molecules in a cubic millimetre of atmospheric air is about a unit-eighteen (10^{18}). (See Phil. Mag., August, 1868.) Whence the average interval between them is about a ninth-metre. This is the 100,000th part of the length of our tiny tube and the 250th part of its breadth. Hence the tube will contain a vast number of molecules, some such number as five thousand millions. Again, the average striking distance (*i.e.*, the average length of path between the encounters) of the molecules is about the 1,500th part of the length of the tube, or the fourth part of its breadth. There is, therefore, abundant room within the tube, small as

it is, for a vast number of molecules, and for much jostling amongst them. The temperatures with which we are dealing are such that the average velocity with which the molecules of air dash about may be taken as 500 metres per second; and the molecules meet with so many encounters that the direction of the path of each is changed somewhere about a unit-ten of times (10,000,000,000) every second. To complete the picture we must remember that each molecule is in a state of vigorous internal motion as well as travelling about among its fellows, and that, when an encounter takes place, the energy which passes from one molecule to another is employed in changing both these kinds of motion, and possibly (but not probably) another part becomes potential energy, *i.e.*, energy expended in altering the configuration of the parts of the molecule, or the position of its parts with reference to the ether. The motions which go on within the molecules are what give rise to the linear spectra of gases, and are, therefore, those motions of the gas that act on the ether and are in turn partly controlled by it.* They are recurring motions which, at least in some cases, are resolvable either into harmonics like the vibrations of a string, or else into quasi-harmonics, not to be distinguished from harmonics by observation (See Donkin's "Acoustics," §194), like the transverse vibrations of an elastic rod—probably the former. On the more probable supposition that they are true harmonics, the periodic times have been determined with great precision in some cases, notably in the cases of a motion within the molecules of hydrogen, which gives rise to three of its spectral lines, and a motion within the molecules of Chlorochromic Anhydride, which gives rise to 105 of its spectral lines. In hydrogen the motion is repeated as often as 2,280,000,000,000 times each second in every molecule, and in the vapour of Chlorochromic Anhydride, rather more than 800,000,000,000 times.† Such are the periodic times on the supposition that the motions are resolvable into true harmonics; and whether the fact be that the components of the motions are harmonics or quasi-harmonics, their periodic times are at all events quantities of this order. The general presumption, therefore, is that the periodic times within

* May we not look, with some prospect of success, to the control which is exercised by the ether on the internal motions of the molecule, for the explanation of the number of "degrees of freedom" of a molecule, which (on the supposition that there is no potential energy) is in most gases 5 (see Watson's "Kinetic Theory of Gases," p. 39). The number 5 appears to indicate that the motions within the molecules are trammelled, as here suggested. This view is, moreover, supported by the fact that light is emitted by the gas, which could not be the case unless vast numbers of molecules moved in unison with one another, and the most probable account of this appears to be that they are all trammelled in the same way by their common relation to the ether.

† The periodic times deduced from the observations are respectively $\frac{\tau}{76{\cdot}18}$ and $\frac{\tau}{2{\cdot}70}$, τ being the time that light takes to advance one millimetre in vacuo. (See Phil. Mag., April, 1871, p. 295, and July, 1871, p. 45. In the former paper read 0·013127714 for 0·13127714.) The first of these determinations was made by the present author, and the second by the present author, in conjunction with Professor Emerson Reynolds, of Dublin; but before either of these determinations were made Professor Clifton, of Oxford, had mentioned at the Exeter meeting of the British Association in 1869, that he had found two of the hydrogen lines (probably C and h) to be related harmonically. I am not aware that any record of this important observation has been published.

the molecules of other gases are also quantities of this order. But it is not necessary for our present purpose to establish this. The only circumstance relating to these inner motions with which we are here directly concerned is that the energy which is transferred from molecule to molecule, is employed partly in altering the velocities with which the molecules travel about and partly in altering these internal motions and (perhaps) collocations; and that the proportion of the energy which is employed in the former way bears on the average a numerical ratio to the whole energy transferred, which can be determined experimentally (see Maxwell's "Theory of Heat," p. 299), and is denoted in the sequel by $\frac{1}{\beta}$.

10. We may now proceed to determine limits between which the thermal and mechanical properties of the gas must lie. For this purpose let us imagine a tube of the kind described above, with perfectly reflecting sides. Such a tube exerts no friction on gas flowing along it, nor does it occasion any loss of energy. Let it contain a large number of gaseous molecules between pistons at temperatures T_1 & T_2. And let us further suppose that the molecules of the gas, according as they leave either piston, acquire the property of not interfering with or being obstructed by the molecules that have last left the other. This imaginary state of the gas would result in two streams constantly travelling in opposite directions along the tube. Let us follow one of these streams. It starts from its piston with a mean of the squares of the velocities of its molecules v_1^2 determined by the temperature of the piston; and in numbers per unit of time represented by $\rho' u'$, ρ' being the density of the stream and u' the average of the normal components of the velocities at starting. Then, however the velocities and directions may have been distributed at starting, *the jostling of the molecules of this stream among one another will reduce the stream as it advances to the condition of unpolarized gas travelling along the tube with the velocity u'.* The molecules are henceforward moving with velocities among themselves which, measured from their advancing centre of mass, has an average square of the velocities w'^2 which is given by the equation

$$\beta v_1^2 = u'^2 + \beta w'^2 \quad . \; . \; . \; . \; . \quad (1)$$

β being the known numerical coefficient representing the ratio of the total energy of the gas to its "energy of agitation." This equation is only the symbolical expression of the fact that no energy has entered or left the gas. The stream moving in the opposite direction furnishes the similar equation

$$\beta v_2^2 = u''^2 + \beta w''^2 ; \quad . \; . \; . \; . \quad (2)$$

And since the numbers of molecules reaching and receding from each piston are equal, we have the further equation.

$$\rho' u' = \rho'' u'' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

We have also

$$\rho = \rho' + \rho'' \quad . \; . \; . \; . \; . \; . \; . \; . \quad (4)$$

Of the quantities which enter into these equations ρ the density of the gas is known, and v_1, v_2, u', and u'', are known functions of T_1 and T_2, the temperatures of the pistons. Hence these equations enable us to determine the remaining quantities ρ', ρ'', w', and w''.

Now, under the conditions that have been laid down, it is manifest that the stress* of the gas sideways would be

$$P_y=\tfrac{1}{3}\rho' w'^2+\tfrac{1}{3}\rho'' w''^2 \quad \text{. . . . .} \quad (5)$$

while the stress along the tube would be

$$P_x=\tfrac{1}{3}\rho' w'^2+\tfrac{1}{3}\rho'' w''^2+\rho' u'^2+\rho'' u''^2 \quad \text{. .} \quad (6)$$

which accordingly, exceeds the transverse stress by

$$\kappa=\rho' u'^2+\rho'' u''^2 \quad \text{. . . . .} \quad (7)$$

This, therefore, would be the Crookes's stress in the case supposed. It is a very large quantity, since u' and u'' would be large if the streams could penetrate one another without obstruction. The flow of heat, which we will designate by the symbol G, would also be very large in the case supposed. An expression for it can be easily found, but is not required for our present purpose.

11. The other limit is one that really occurs. It arises when the molecules coming up to either piston, and those retiring from it form complementary parts such that their coexistence in the same space constitutes stationary unpolarized gas. This happens only when the two pistons are at the same temperature. In this case it is manifest that no heat is conveyed by the gas, and that the gas exerts the same pressure in all directions. In symbolical language—

$$G=0$$
$$\kappa=0$$

G being, as before, the symbol for the flow of heat, and κ for the Crookes's stress. This case may be described as one in which the streams described in the last section experience such effectual opposition from each other that the speed with which they advance is reduced to zero. For it is evident that the gas at any station within the tube may, without any change of its properties, be described as consisting of two equal portions of stationary unpolarized gas, coexisting in the same space.

12. In all other cases the pistons that close the ends of the unit tube are at different temperatures, and the gas between any two cross sections of the tube is polarized. Let us consider a slice between two such sections, which are sufficiently close to entitle us to regard the included gas as being throughout in nearly the same state. The actual condition of the gas within the slice may evidently be conceived of as arising from the coexistence of two streams travelling in opposite directions along the tube, and each consisting of gas which is less polarized, *i.e.*, which deviates less from the condition of ordinary gas, than the gas that results

* The term stress is here applied to the *pressure* within the gas in any direction viewed in conjunction with the equal pressure in the opposite direction. It is what Clausius has called "the positive momentum," meaning thereby the sum of the components of the momenta of the molecules resolved in a given direction, and all estimated as positive, whether of molecules that move forward or backward.

from their coexistence. Each stream is exposed within the slice to the mutual jostling of its own molecules, and it is also attacked by molecules of the other stream. The mutual jostling of its own molecules tends, as explained in section 10, both to maintain the onward velocity of the stream and to reduce the gas of which the stream consists still more towards the condition of unpolarized gas. These encounters, then, taken by themselves, tend to bring about the state of the gas described in section 10. But the interference of the two streams with one another counteracts this. This interference modifies the effect of the encounters within the streams, but it is incompetent to annul it. For the two streams do not by their mere coexistence constitute stationary unpolarized gas, and hence they would need time before they could by their action upon one another reduce the gas to this condition. It is, however, plain that whatever action they exert is a step towards bringing about this condition; for the gas would become depolarized if the cross sections which bound the slice could be rendered impervious both to energy and molecules, so as to leave the two streams time to act fully on one another. In reality, however, sufficient time is not allowed to them, because the streams pass one another, and the struggle is continually renewed within the slice by fresh portions of the streams which come up *in the same state* as those that had been obliged to pass on. These fresh portions keep in the same state because a sufficient supply of swift molecules is without intermission being thrown back along the tube from one end by the heater, and a corresponding supply of slow molecules from the other end by the cooler.

13. The two streams, though not annulled, are, however, different from what they would have been if they had been without influence upon one another. They do not consist of the same molecules from one instant to another, for there is such a perpetual shifting of molecules between them, owing to the vast number of encounters that take place, that no one molecule is likely to remain long in one stream. Again, after an encounter between molecules of the two streams both of the colliding molecules will sometimes join the same stream, and it will most frequently happen that the stream so joined is the hotter and swifter stream. Hence the stream from the heater to the cooler receives an accession to the number of its molecules as it travels forward, while the reverse effect is produced upon the stream making its way in the opposite direction. On both accounts there will be gradients of density and temperature along the tube between the heater and cooler. Again, every encounter between molecules of the two streams diminishes the momentum of one or both streams; but, as we have seen, the effect so produced does not go the length of reducing the streams to rest.

14. Hence we must bear in mind the gradients of temperature and density along the two streams, and the continual fluctuation of the molecules that are to be referred to them, if we want to regard the condition of the gas throughout the whole length of the tube as arising out of the coexistence of two streams of gas less polarized than itself. But with these precautions the hypothesis may be made, and accordingly the condition of the gas at every cross section of the tube *is intermediate between a structure represented by the coexistence of the two streams*

of unpolarized gas travelling simultaneously in opposite directions, which the encounters within each stream tend to develop, *and the condition of stationary unpolarized gas,* towards which the mutual interference of the two streams modifies the structure. Hence there is some polarization stress and some flow of heat all along the tube, though of less amount than in the case considered in section 10. We may still employ equation (7) as the expression for the polarization stress, if we use for ρ' and ρ'' the densities of the streams at some particular cross section of the tube, and if u' and u'' are modified into what they become as the interference of the two streams with one another is increased. It is not necessary to ascertain what this modification will be; it is enough for our purpose to know that u' and u'' will be some functions of $V' - V''$ (where V'^3 and V''^3 are the averages of the cubes of the velocities of the molecules that pass forwards and backwards respectively through the cross section), and that they will be proportional to this quantity when all three are small.

15. We may base upon this circumstance an investigation of the laws of the phenomenon when the difference between the temperatures of the heater and cooler is small compared with their absolute temperatures. This case is of importance because it is that which most frequently occurs, and is the only one in reference to which accurate experiments have been made. In this case ρ' and ρ'' will each be nearly $\frac{1}{2}\rho$ using ρ for the density of the gas at the position in the tube which we are considering; and $V' - V''$ being small may be appropriately represented by δV. Then, remembering that u' and u'' are proportional to δV, we obtain from equ. (7) the following expression for the polarization stress—

$$\kappa \propto \rho(\delta V)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Where the symbol $\propto$ means *approximately varies as.* Moreover, it can be shown*

* One of the ways in which this may be proved is the following :—
Clausius has shown (*Phil. Mag.*, vol. 23, p. 514) that

$$G = \tfrac{1}{4}\beta\rho \int_{-1}^{+1} \mathrm{I}\overline{V^3}\mu d\mu$$

whence

$$G = \tfrac{1}{8}\beta\rho(\mathrm{I}'V'^3 - \mathrm{I}''V''^3)$$

where I' and V'^3 are the average values of I and $\overline{V^3}$ under the integral for positive values of μ, *i.e.*, for molecules traversing the section of the tube towards the cooler; and I'' and V''^3 are the corresponding averages for negative values of μ, *i.e.*, for molecules traversing the section of the tube in the opposite direction.

Now, it is evident that these quantities are capable of expansion in the following form :—

$$\mathrm{I}' = 1 + A_1\frac{\delta V}{V} + A_2\frac{(\delta V)^2}{V^2} + \ldots$$

$$\mathrm{I}'' = 1 + B_1\frac{\delta V}{V} + \ldots$$

$$V'^3 = V^3(1 + C_1\frac{\delta V}{V} + \ldots)$$

$$V''^3 = V^3(1 + D_1\frac{\delta V}{V} + \ldots)$$

in which V^3 is the average of the values of $\overline{V^3}$ for all directions. Whence

$$G = \tfrac{1}{8}\beta\rho(A_1 - B_1 + C_1 - D_1)V^2\delta V$$

+ terms containing higher powers of δV.

from various considerations that the flow of heat

$$G \propto \rho V^2 \delta V$$

or, by a simple transformation,

$$G \propto \rho T . \delta V \; . \; . \; . \; . \; . \; . \; (9)$$

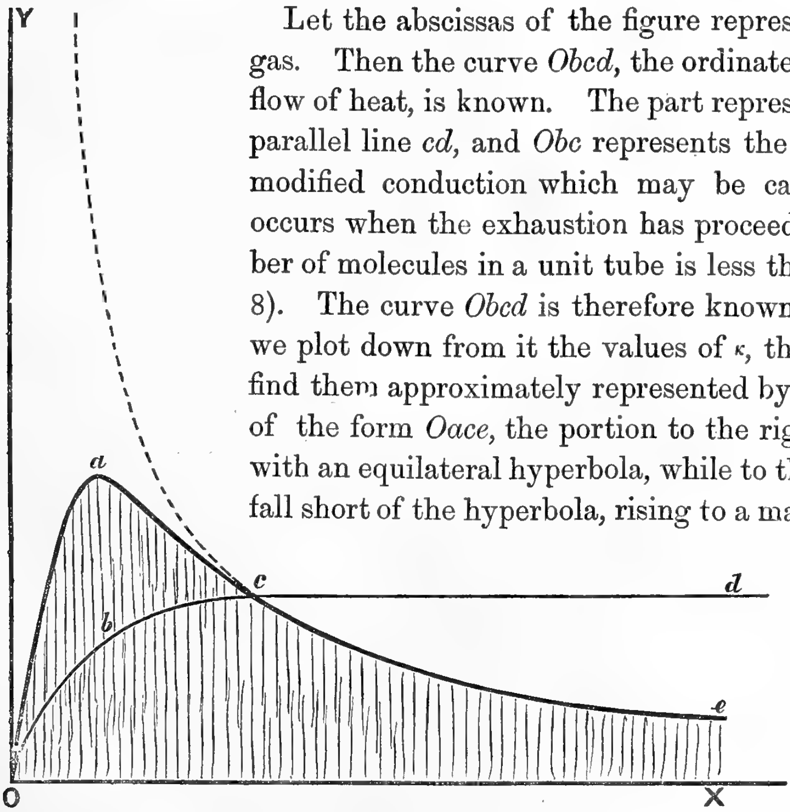
T being the temperature measured from absolute zero. Hence from the approximate equations (8) and (9) we obtain the equation—

$$\kappa \propto \frac{G^2}{\rho T^2} \; . \; . \; . \; (A)$$

which contains only quantities of which we already know enough to make use of them. Equ. (A), may be thrown into a still more convenient form by writing P for the tension of the surrounding atmosphere of gas, which is nearly the same as the stress which the gas at the station we are considering would exert if de polarized. P will therefore vary nearly as ρT, whence—

$$\kappa \propto \frac{G^2}{PT} \; . \; . \; . \; (B)$$

16. As an example of the application of these approximate formulæ, let us plot down on a diagram the value of κ, the polarization stress, for various tensions of gas between a heater and cooler at constant temperatures and at a fixed distance asunder.



Let the abscissas of the figure represent the tensions of the gas. Then the curve *Obcd*, the ordinates of which represent the flow of heat, is known. The part representing conduction is the parallel line *cd*, and *Obc* represents the outflow of heat by that modified conduction which may be called penetration, which occurs when the exhaustion has proceeded so far that the number of molecules in a unit tube is less than N (see above, section 8). The curve *Obcd* is therefore known, and if by equation (B) we plot down from it the values of κ, the polarization stress, we find them approximately represented by the ordinates of a curve of the form *Oace*, the portion to the right of *c* being coincident with an equilateral hyperbola, while to the left of *c* the ordinates fall short of the hyperbola, rising to a maximum and then falling off to zero. The position of this maximum cannot be obtained with certainty, because equation (B) is less to be depended on at *very* low tensions. Bearing this in mind, the accordance of the theoretic values with those determined experimentally by Mr. Crookes and Mr. Moss, is satisfactory.

17. From equation (B), we may obtain another useful formula which expresses the approximate law according to which polarization stress depends upon the interval between heater and cooler, whenever this interval exceeds the limit determined by the condition that there shall be a sufficient number of molecules in the unit tube to allow heat to pass by conduction.

In this case we know the equation of the gradient of temperature (see Clausius's equation 54, Phil. Mag. vol. 23, p. 527), and that it is approximately represented by a straight line when, as we have assumed, $\frac{\Delta T}{T}$ is small, using ΔT for the difference between the temperatures of the heater and cooler. Hence, and from Clausius's equation 56, it appears that—

$$\frac{G^2}{T} \propto \frac{(\Delta T)^2}{X^2}$$

using X for the distance between the heater and cooler. Introducing this value into equation (B), we find—

$$\kappa \propto \frac{(\Delta T)^2}{PX^2} \quad . \quad . \quad . \quad (C)$$

a result which agrees satisfactorily with Mr. Moss's experiments.

18. If we use X_0 for that interval between heater and cooler which would make the number of molecules in the unit tube equal to N, and if we use κ_0 for the corresponding value of the Crookes's stress, then equ. (C), and the obvious equation $X_0 \propto \frac{1}{P}$, furnish us with the following—

$$\kappa_0 \propto P.(\Delta T)^2 \quad . \quad . \quad . \quad . \quad (10)$$

Now equation (C) enables us to plot down a *part* of the curve representing the relation between κ and X when ΔT and P are kept constant; and although equation (C) cannot be relied upon when X is less than X_0, it is nevertheless evident that the form of the remainder of the curve must be one which is independent of the particular value of P which we have used. Hence if $\bar{\kappa}$ is the maximum value of κ in that curve, it follows that $\bar{\kappa}$ and κ_0 must remain proportional to one another when P is changed. Hence equation (10), furnishes—

$$\bar{\kappa} \propto P.(\Delta T)^2 \quad . \quad . \quad . \quad . \quad (D)$$

We learn from this inquiry that the maximum polarization stress which can be elicited between a given heater and cooler by varying the distance between them will, if the tension of the gas is altered, change in the same ratio as that tension, and that it will occur at intervals between heater and cooler which vary inversely as that tension. This fully accounts for the powerful Crookes's force which presents itself in experiments at ordinary atmospheric tensions as compared with the feeble force exhibited in radiometers. It accounts also for the very short interval at which the heater and cooler must be placed when the gas is dense.

PART 2.—INVESTIGATION OF A COMPLETE EXPRESSION FOR THE STRESS.

18. As it has been asserted ("Nature," vol. 17, p. 122,) that the views of the present writer are at variance with the results established by previous investigators, I will proceed to show that the theory of unequal stresses which I have put forward is, on the contrary, the necessary sequel of them. I will show this by continuing the method of investigation commenced by Professor Clausius in his memoir on "the conduction of heat by gases," in the way which was pointed out by Mr. George F. Fitzgerald in "Nature," vol. 17, p. 200. This inquiry will have the further advantage of furnishing a complete expression for Crookes's stress.

19. Clausius (Phil. Mag., vol. 23, p. 514) has given the following expression for the stress across a layer of gas conducting heat, in the direction *normal* to a heater and cooler, the opposed surfaces of which are parallel and extensive—

$$P_x = \tfrac{1}{3}\rho v_y^2 + X_1\epsilon^2$$

ϵ being a small quantity of the same order as the striking distance of the molecules, and X_1 being a coefficient of which Clausius did not compute the value, as the scope of his investigation only required him to go as far as the first order of small quantities. Now Mr. Fitzgerald in his letter to "Nature," and more fully in conversation with the writer, pointed out that if an expression for P_y, the stress *parallel* to the surfaces of the heater and cooler, were calculated by a method similar to Clausius's, the coefficient of ϵ^2 in this expression could not be the same as X_1, and that hence there *must* be a difference between the two stresses, in other words a polarization stress.

20. Clausius (loc. cit.) gives the following general expression for the normal stress

$$P_x = \tfrac{1}{2}\rho\int_{-1}^{+1} I\overline{V^2}\mu^2 d\mu \quad . \quad . \quad . \quad . \quad (11)$$

where I is the coefficient expressing the proportion of molecules travelling in the directions which make an angle with the normal or axis of x of which the cosine is μ; and where $\overline{V^2}$ is the mean of the squares of their velocities.

Now if, employing a process exactly similar to that pursued by Clausius on pp. 512 and 513 of his memoir, we use N for the number of molecules in a unit of volume, then will Ndr be the number of molecules within a slice of unit area and thickness dr, which we may suppose to be placed perpendicular to the vector r. Then

$$\frac{1}{4\pi}\,\mathrm{NI}\,dr\,d\sigma$$

will be the number of molecules moving within the slice in directions which lie within an element of solid angle $d\sigma$, which we will suppose makes the angle ψ with the vector r, so that the time they take to cross the slice will be

$$\frac{dr\,.\,\sec\psi}{\mathrm{V}}$$

V being their velocity. Hence the number traversing the slice in the specified direction within a unit of time is

$$\frac{1}{4\pi}\,.\,\mathrm{NIV}\cos\psi\,.\,d\sigma.$$

Multiplying this by $m\mathrm{V}\cos\psi$ we get the resolved part of their momenta along r. The sum of all such components of the momenta, all estimated as positive, is P_r, the stress in the direction of r. Whence, and writing ρ for m N, we find

$$\mathrm{P}_r=\frac{\rho}{4\pi}\iint\overline{\mathrm{IV}^2}\cos^2\psi d\sigma$$

the integration being extended over the unit sphere.

Hence the stresses in the directions of three rectangular axes are

$$\mathrm{P}_x=\frac{\rho}{4\pi}\iint\overline{\mathrm{IV}^2}\,\mathrm{co}^2\alpha d\sigma$$

$$\mathrm{P}_y=\frac{\rho}{4\pi}\iint\overline{\mathrm{IV}^2}\,\mathrm{co}^2\beta d\sigma$$

$$\mathrm{P}_z=\frac{\rho}{4\pi}\iint\overline{\mathrm{IV}^2}\,\mathrm{co}^2\gamma d\sigma$$

$\alpha\,\beta\,\gamma$ being the director angles of the element of solid angle $d\sigma$. Introducing polar co-ordinates, we have

$$d\sigma=\sin\theta\,d\theta\,d\phi$$
$$\cos\alpha=\cos\theta$$
$$\cos\beta=\sin\theta\cos\phi$$
$$\cos\gamma=\sin\theta\sin\phi$$

by which the expressions for the stresses become

$$\left.\begin{aligned}
\mathrm{P}_x&=\frac{\rho}{4\pi}\int_0^{2\pi}\int_0^{\pi}\overline{\mathrm{IV}^2}\cos^2\theta\sin\theta d\theta d\phi\\
\mathrm{P}_y&=\frac{\rho}{4\pi}\int_0^{2\pi}\int_0^{\pi}\overline{\mathrm{IV}^2}\sin^3\theta\cos^2\theta d\theta d\phi\\
\mathrm{P}_z&=\frac{\rho}{4\pi}\int_0^{2\pi}\int_0^{\pi}\overline{\mathrm{IV}^2}\sin^3\theta\sin^2\theta d\theta d\phi
\end{aligned}\right\}\ \text{(E)}$$

These are the most general expressions for the stresses in three rectangular directions within gas polarized in any way; and they will be the only stresses between portions of the gas separated by planes parallel to the planes yz, zx, xy, if the axes are so chosen that there are no moments round them arising from the molecular encounters*.

21. This condition is easily secured in the case which we are investigating, viz., when heat is making its way between a heater and cooler that are paralled to one another, and of large extent compared with the interval between them; since the

* Equations (E) cannot be integrated unless $\overline{\mathrm{IV}^2}$ is given as a function of θ and ϕ, *i.e.*, unless the law of polarization in the gas is known. But they show that in general *the stresses in different directions are unequal*, which is here what is chiefly insisted on.

When the gas is unpolarized, I becomes equal to unity, and $\overline{\mathrm{V}^2}$ is independent of the direction, and may therefore be put outside the integrals. In this case all three equations concur in giving the well known expression for the stress in unpolarized gas, viz., $\frac{1}{3}\rho\overline{\mathrm{V}^2}$.

polarization of the intervening gas will evidently be disposed symmetrically round the direction in which the heat is travelling. Hence, taking this direction as our axis of x, there can be no moments round this axis, or round any axis at right angles to it. The stresses (E), therefore, are the only ones to be taken into account. Moreover, we can integrate equations (E) at once by ϕ, since $\mathrm{I}\overline{\mathrm{V}^2}$ is, in this simple case, a function of θ only. Doing this, and writing μ for cos θ, we find

$$\left.\begin{aligned} P_x &= \frac{\rho}{2}\cdot\int_{-1}^{+1} \mathrm{I}\overline{\mathrm{V}^2}\,\mu^2 d\mu \\ P_y = P_z &= \frac{\rho}{4}\int_{-1}^{+1} \mathrm{I}\overline{\mathrm{V}^2}\,(1-\mu^2) d\mu \end{aligned}\right\} \quad (\mathrm{F})$$

Whence, since κ, the polarization stress, $=P_x-P_y$, we have finally

$$\kappa=\frac{\rho}{4}\int_{-1}^{+1} \mathrm{I}\overline{\mathrm{V}^2}\,(3\mu^2-1)d\mu \quad \ldots . \text{(G)}$$

This then is the complete mathematical expression for Crookes's stress. It could be integrated if we knew the law of the polarization of the gas, for then $\mathrm{I}\overline{\mathrm{V}^2}$ would be a known function of μ.

22. Clausius, in investigating the diffusion of heat across the layer of gas, makes the assumption (Phil. Mag. Vol. 23, pp. 425 and 524) that the numbers and velocities of the molecules "emitted" by a thin stratum of the gas (*i.e.* that have passed out of the stratum after having encountered other molecules within it) may be adequately represented "by assuming at first motions taking place equally in all directions, and then supposing a small additional component velocity in the direction of positive x to be imparted to all the molecules." In other words, it is assumed that the motions of these molecules may be represented by radii vectores from a slightly excentric origin to points equally distributed over the surface of a *sphere.* It will be instructive to trace the consequences of this hypothesis, both because of what it will do and what it will not do.

Upon this hypothesis Clausius finds the following convergent series for $\overline{\mathrm{V}^2}$ and I (loc: cit: pp. 434 and 516)

$$\overline{\mathrm{V}^2}=u^2+2uq\mu\epsilon+(2ur+q_1^2)\mu^2\epsilon^2+\ldots .$$

$$\mathrm{I}=(1-\tfrac{1}{3}r'\epsilon^2+\ldots .)-\frac{q}{u}\cdot\mu\epsilon+r'\mu^2\epsilon^2+\ldots$$

where $\frac{1}{5}q\epsilon$ (p. 525) is the small component velocity spoken of above, u is the mean velocity of molecules moving in the plane yz, and the other letters have the meanings assigned to them by Clausius. Multiplying these together, going to the second order of small quantities, and arranging by powers of μ, we find

$$\mathrm{I}\overline{\mathrm{V}^2}=u^2(1-\tfrac{1}{3}r'\epsilon^2)+\mathrm{A}_1\mu\epsilon+\mathrm{A}_2\mu^2\epsilon^2 \quad \ldots . \text{(12)}$$

where

$$\mathrm{A}_2=-2q^2+2ur+q_1^2+u^2r' \quad \ldots\ldots \text{(13)}$$

Introducing the expression (12) into equations (F) and (G) we find

$$\left.\begin{aligned} P_x &= \tfrac{1}{3}\rho u^2(1-\tfrac{1}{3}r'\epsilon^2)+\tfrac{1}{5}\rho\mathrm{A}_2\epsilon^2+\ldots \\ P_y = P_z &= \tfrac{1}{3}\rho u^2(1-\tfrac{1}{3}r'\epsilon^2)+\tfrac{1}{15}\rho\mathrm{A}_2\epsilon^2+\ldots \\ \kappa &= \tfrac{2}{15}\rho\mathrm{A}_2\epsilon^2+\ldots \end{aligned}\right\} \quad (14)$$

In these A_2 stands for the expression (13) ; and introducing the following values which are given by Clausius as correct to the second order of small quantities (loc: cit: p. 526, footnote.)

$$q^2{}_1=\frac{41}{25}q^2$$

$$ur=-\frac{31}{50}q^2$$

$$u^2r'=\frac{266}{17\cdot25}q^2$$

We find—

$$A_2=13\cdot8\ q^2$$

From this and (14)

$\kappa=1\cdot8\times\rho q^2\epsilon^2+$ terms of the fourth and higher orders. (15).

But by Clausius's theory (loc: cit: p. 516)

$G=\frac{1}{3}\beta\rho u^2q\epsilon+$ terms of the third and higher orders. (16).

Whence, approximately, omitting the fourth and higher orders of small quantities, and writing v for u, since they are nearly equal, and then putting P for its equivalent $\frac{1}{3}\rho v_2$

$$\kappa=1\cdot8\frac{\rho G^2}{\beta^2P^2}\ \ldots\ldots\ (17)$$

Now, by Boyle's law $\frac{P}{P_o}=\frac{\rho T}{\rho_oT_o}$, where P_o, ρ_o, and T_o have reference to standard temperature and pressure. Whence, finally

$$\kappa=\left[(1\cdot8)\frac{\rho_oT_o}{\beta^2P_o}\right]\cdot\frac{G^2}{PT}\ \ldots\ldots\ (18)$$

An equation which assigns the same law as we obtained above in equ. (B) by the wholly different method of direct mechanical considerations.

23. Equation (18) *appears* to give also the amount of the polarization stress. But this is illusory. The hypothesis upon which it rests is adequate as regards the conduction of heat, but is insufficient for a quantitative investigation of the stress, as I will now proceed to show.

The general formulæ for the conduction of heat and for the polarization stress are the following—

$$G=\frac{1}{4}\beta\rho\int_{-1}^{+1}\overline{IV^3}.\mu d\mu$$

$$\kappa=\frac{1}{4}\rho\int_{-1}^{+1}\overline{IV^2}.(3\mu^2-1)d\mu$$

(See Clausius's memoir p. 514, and equation (G) above). Now, μ and $3\mu_2-1$, which occur as factors in these integrals are the first and second terms of a series of spherical harmonics (Laplace's co-efficients) of the simple kind that are functions of μ only, and which therefore represent the radii of solids *of revolution* from points on their axes. It is moreover obvious that we can expand $\overline{IV^2}$ and $\overline{IV^3}$ in series

of spherical harmonics of the same simple type. Doing this—

$$\overline{\mathrm{IV}^3}=g_0+g_1+g_2+\ldots$$
$$\overline{\mathrm{IV}^2}=k_0+k_1+k_2+\ldots$$

the g's and k's representing spherical harmonics. Whence, and from the fundamental property of spherical harmonics—

$$G=\tfrac{1}{4}\beta\rho\int_{-1}^{+1} g_1\mu\delta\mu$$

$$\kappa=\tfrac{1}{4}\rho\int_{-1}^{+1} k_2(3\mu^2-1)d\mu$$

Hence g_1, is the only term of the first series that produces any conduction of heat, and k_2 is the only term of the second series that produces any polarization stress.

Let us suppose radii drawn from a point in all directions of lengths proportional to the values of $\overline{\mathrm{IV}^2}$ in those directions. We thus obtain a solid of revolution which may also be arrived at by plotting down radii equal to k_0, and successively correcting the solid so found by the addition of k_1, k_2, &c., to its radii. Now—

$$k_0=\mathrm{A}$$
$$k_1=\mathrm{B}.\mu$$
$$k_2=\mathrm{C}.(3\mu^2-1),$$
$$\&c., \qquad \&c.$$

Where A, B, C, &c., are independent of μ. In the case we are considering B, C, &c., are small compared with A. From the foregoing values it follows that if k_0 is plotted down by itself it will produce a sphere with its centre at the origin of radii. Next, k_0+k_1 may be plotted down by shifting the centre of this sphere through the small distance B towards positive x, and by then very slightly distorting the form of the sphere. Again, to plot down k_0+k_2, we should elongate the sphere in the direction of the axis x by an amount equal to 4C and narrow it equatorially by an amount equal to 2C, without shifting its centre. Finally $k_0+k_1+k_2$ would be represented by radii drawn to the surface of this last solid, after it had been slightly distorted and removed through the distance B towards the cooler. Through these mutations the mean value of all the radii drawn from the origin remains unaltered.*

Comparing these figures with expansion (12), which is the value for $\overline{\mathrm{IV}^2}$ furnished by Clausius's hypothesis, we find that the form and position of the solid which

* Since, by the fundamental property of spherical harmonics,

$$\int_{-1}^{+1} k_1 d\mu=0$$

$$\int_{-1}^{+} k_2 d\mu=0$$

&c.

results from plotting it down are such that (owing to the term containing μ) there is that separation between the origin of radii and the centre of figure which gives a sufficient value to the function k_1, but that (the co-efficient of μ^2 containing only very small quantities) the solid is not elongated in the way which would allow the function k_2 to attain any considerable value. That the function k_2 is not *wholly* absent, is because of such causes as the slight distortion of figure before mentioned, which give rise to very small* terms of the form k_1, k_2, &c.

This almost total absence of the elongated form arises from Clausius's fundamental hypothesis that the motions of the molecules emitted by a stratum may be represented by radii drawn to a *sphere* from an excentric point, whereas it appears from the discussion in the earlier part of the present memoir that the encounters that take place within each of the two streams into which the gas may be divided, give to the surface to which the radii are to be drawn an elongated form. This omission from Clausius's hypothesis does not sensibly affect the spherical harmonics of the *first* order, and accordingly his hypothesis is adequate as regards the flow of heat, which depends exclusively on one of these; but it renders the hypothesis an insufficient one as regards polarization stress, or any other phenomenon which depends on spherical harmonics of the *second* order.

* That k_2 is very small, if we adopt Clausius's hypothesis, may also be seen by comparing equation (18) with experiments on spheroidal drops. Observation shows that, at atmospheric temperatures and pressures, a spheroid of water some millimetres in diameter will be supported at a distance of about a fourth-metre (a metre divided by 10^4) from the heater, when the difference of temperatures is about 10°C. In G C S (gramme, centimetre, second) systematic measures, the hyper-milligram, ($\frac{10}{g}$ of the gravitation of a milligram, g being gravity measured in metres per second per second) per square centimetre is the unit of stress. Hence the Crookes's stress which supports this drop must amount to some hundreds of these units. This is the amount indicated by experiment.

Formula (18) assigns to it a very different value. Clausius estimates the flow of heat across air between a heater and cooler each a square metre in surface and a metre asunder, and kept at temperatures which differ by 1° C., as amounting per second to $\frac{11}{4000000}$ of the quantity of heat which will warm a kilogram of water 1°C. About ten times this, or $\frac{11}{400000}$ of this calory per second, would be the flow of heat between two square centimetres at a distance of a fourth-metre asunder and kept at temperatures that differ by 10°C. To turn this into kinetic measure we must multiply by 41600×1000000; so that G would amount to about 1144000 in G C S kinetic measure (*i.e.* in Hyper-fifth-grammetres per second). Again we may take as rough approximations—

$$\rho_0 = \frac{1}{800}$$
$$T_0 = T$$
$$\beta^2 = 2{\cdot}6$$
$$P_0 = P_1 = 1000000$$

Introducing these values into equation (18) we find approximately—

$$\kappa = 0{\cdot}001$$

of a hyper-milligram per square centimetre—an amount which, as it ought to be, is vastly smaller than that indicated by experiment.

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V.—*On the Mechanical Theory of Crookes's Force.* By George Francis Fitzgerald, M.A., F.T.C.D. [Read March 18th, 1878.]

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V.—ON THE MECHANICAL THEORY OF CROOKES'S FORCE,

BY

GEORGE FRANCIS FITZGERALD, M.A., F.T.C.D.

[Read March 18th, 1878.]

When two surfaces at different temperatures are in presence of one another with a gas between them, there exists a force tending to separate them. The assumption of this force explains a very great number of phenomena including the motion of the arms in Mr. Crookes' radiometers, and the so-called spheroidal state of liquids. That this force was due to some sort of unequal stress in the gas between the two surfaces, was pointed out by Mr. Stoney, in the Phil. Mag., March and April, 1876, where he attempted to show that such a state of stress would arise. An attempt to explain the motion of the arms of a radiometer had been made previously, by Professor O. Reynolds, but his conclusion, that it was principally due to evaporation and condensation, is manifestly inadequate to explain a continuous action, such as that in a radiometer, and the method by which he tried to show that a surface when communicating heat to gas is subject to an increased presure, is open to the overwhelming objection, that this increased pressure would be almost instantaneously transmitted to all parts of the enclosed gas, and so could not possibly be the source of such a force as would explain the motion of the arms of a radiometer.

In amplification of a letter I wrote to "Nature" on the 17th of December, 1877, and which was published on the 4th of January, 1878, I now intend to prove that such a state of stress as Mr. Stoney's theory requires, would exist under the assumed conditions. My letter contains a proposed application of Clausius' investigation for finding the conducting power of a gas, as published in the Philosophical Magazine, Vol. 23, 4th Ser. Mr. Stoney, in a paper read before the Royal Dublin Society, on Monday, the 18th of February, 1878, has obtained results somewhat like those obtained by my method, by applying a method similar to one he originally employed.

I may first observe, that the only way in which a state of other than uniform stress can exist in a gas, is by the distribution of the mean velocities, and number of molecules being different in different directions, or, as Mr. Stoney has called it, by the gas being polarized. That the distribution is not uniform when heat is being conducted through a gas, has been pointed out long ago by both Clausius and Maxwell, and what is required, is to show that the distribution will then be such as to develope a force like Crookes'.

Following the method adopted by Clausius in his paper already referred to, I assume that the mean velocity of a molecule is a function of its direction of motion, and that the number of molecules in the unit volume moving in a given direction, is also a function of that direction. If, then, we define the direction by means of μ, the cosine of the angle it makes with a given direction, ϕ, the angle the plane of these two directions make with a fixed plane through the given direction we may evidently assume,

$$v=v_o f(\mu\phi) \qquad n=n_o F(\mu\phi)$$

Where v and n are the mean velocities, and number of molecules moving in this direction, and v_o and n_o are certain given values of v and n when f and F are unity. Now we may evidently in addition take $n_o=\frac{N}{4\pi}d\mu d\phi$ where N is the total number of molecules per unit volume, so that we have generally

$$n=\frac{N}{4\pi}F(\mu,\phi)d\mu d\phi.$$

The quantities I intend to calculate are, the number of molecules carried through the unit area in any direction, the total momentum carried through the same, and the quantity of energy carried through it. The number of molecules going in one direction through the unit area, must evidently be equal to that of those going in the opposite direction, if there are no gaseous currents going on, and, even if present, their existence is evidently beside the question in hand. Hence, if we sum the number of molecules passing the unit area, taking those that go in opposite direction through it with opposite signs, the sum must vanish. I shall calculate the numbers in three cases of unit areas, 1st, perpendicular to the line from which μ is measured, or X; 2nd, parallel to the plane from which ϕ is measured, *i e.*, perp. to Y; and 3rd, for the case of a unit area perpendicular to these two, *i.e.*, perp. to Z. The number of molecules going in the direction (μ, ϕ), that pass through the first of these per unit of time, is evidently $= n\ v\ \mu$ and it is likewise evident that the number going in the opposite direction will have an opposite sign, so that we have the sum of all such zero. Similarly for the other two planes the numbers are

$$nv\sqrt{1-\mu^2}\,.\sin\phi \text{ and } nv\sqrt{1-\mu^2}\,.\cos\phi$$

So that we get

$$0=\Sigma nv\mu=\Sigma nv\sqrt{1-\mu^2}\sin\phi=\Sigma nv\sqrt{1-\mu^2}\,.\cos\phi.$$

The momentum carried through the 1st of these unit areas per unit of time, by molecules moving in the direction, μ,ϕ is $=Mnv^2\mu^2$ if M be the mass of each molecule, and as it does not change sign with μ, we see that the sum of all such will represent the normal pressure per unit area, at the given place. We can similarly get the normal pressures on the other two unit areas, and calling them P_{xx}, P_{yy}, and P_{zz}, we obtain

$$P_{xx}=M\Sigma nv^2\mu^2$$
$$P_{yy}=M\Sigma nv^2(1-\mu^2)\sin{}^2\phi$$
$$P_{zz}=M\Sigma nv^2(1-\mu^2)\cos{}^2\phi$$

Proceeding similarly we can get the tangential pressures on these areas, and we easily see that they are

$$P_{yz}=P_{zy}=M\Sigma nv^2(1-\mu^2)\sin\phi\cos\phi$$
$$P_{zx}=P_{xz}=M\Sigma nv^2\mu\sqrt{1-\mu^2}\,.\cos\phi$$
$$P_{xy}=P_{yx}=M\Sigma nv^2\mu\sqrt{1-\mu^2}\,.\sin\phi$$

If now we proceed to calculate the energy carried across these areas per unit time, we get $k\ n\ v^3\ \mu$ as that carried across the 1st area by molecules moving in the direction μ, ϕ, when k is the coefficient by which the energy of translation must be multiplied, in order to obtain the total energy, calling the quantities of energy Q_x Q_y and Q_z, we thus get

$$Q_x=Mk\Sigma nv^3\mu \qquad Q_y=Mk\Sigma nv^3\sqrt{1-\mu^2}\sin\phi \qquad Q_z=Mk\Sigma nv^3\sqrt{1-\mu^2}\cos\phi$$

In order to be able to perform these summations, it is necessary to know the mean values of nv, nv^2, and nv^3 in terms of μ and ϕ, and I shall, in the first place merely assume that they can be expanded in a series of spherical harmonics, thus :

$$\overline{nv}=\frac{Nv_o}{4\pi}(A_o+A_1+A_2+\ldots\ldots)\,d\mu d\phi$$
$$\overline{nv^2}=\frac{Nv_o^2}{4\pi}(B_o+B_1+B_2+\ldots\ldots)\,d\mu d\phi$$
$$\overline{nv^3}=\frac{Nv_o^3}{4\pi}(C_o+C_1+C_2+\ldots\ldots)\,d\mu d\phi$$

The effect of this is to obtain our former results under the following simplified forms. Our first series of equations gives $A_1=o$ and as A_1 must be of the form

$$A_1=a_1\mu+a_2\sqrt{1-\mu^2}\sin\phi+a_3\sqrt{1-\mu^2}\cos\phi$$

we get $a_1=a_2=a_3=o$

The second system of equations gives

$$P_{xx}=\frac{MNv_o^2}{4\pi}\iint(B_o+B_2)\mu^2 d\mu d\phi$$
$$P_{yy}=\frac{MNv_o^2}{4\pi}\iint(B_o+B_2)(1-\mu^2)\sin^2\phi\ d\mu d\phi$$
$$P_{zz}=\frac{MNv^2}{4\pi}\iint(B_o+B_2)(1-\mu^2)\cos^2\phi\ d\mu d\phi$$
$$P_{yz}=P_{zy}=\frac{MNv_o^2}{4\pi}\iint B_2(1-\mu^2)\sin\phi\cos\phi\ d\mu d\phi$$
$$P_{zx}=P_{xz}=\frac{MNv_o^2}{4\pi}\iint B_2\,\mu\sqrt{1-\mu^2}\cos\phi\ d\mu d\phi$$
$$P_{xy}=P_{yx}=\frac{MNv_o^2}{4\pi}\iint B_2\,\mu\sqrt{1-\mu^2}\sin\phi\ d\mu d\mu$$

If now we assume

$$B_2=b_1(\mu^2-\tfrac{1}{3})+b_2(1-\mu^2)\cos2\phi+b_3(1-\mu^2)\sin\phi\cos\phi$$
$$+b_4\,\mu\sqrt{1-\mu^2}\cos\phi+b_5\,\mu\sqrt{1-\mu^2}\sin\phi$$

as it must be of this form we get on putting our other quantities into the forms of spherical harmonics

$$P_{xx}=\frac{MNv_o^2}{3}(B_o+\frac{4}{15}\cdot b_1)$$

$$P_{yy}=\frac{1}{3}MNv_o^2(B_o-\frac{2}{15}b_1-\frac{2}{5}b_2)$$

$$P_{zz}=\frac{1}{3}MNv_o^2(B_o-\frac{2}{15}b_1+\frac{2}{5}b_2)$$

$$P_{yz}=\frac{1}{15}MNv_o^2\,b_3=P_{zy}$$

$$P_{zx}=\frac{1}{15}MNv_o^2\,b_4=P_{xz}$$

$$P_{xy}=\frac{1}{15}MNv_o^2\,b_5=P_{yx}$$

Similarly for the quantities of energy transferred we get

$$Q_x=\frac{MNv_o^3}{4\pi}k\iint C_1\,\mu d\mu d\phi$$

$$Q_y=\frac{MNv_o^3}{4\pi}k\iint C_1\sqrt{1-\mu^2}\sin\phi\,d\mu d\phi$$

$$Q_z=\frac{MNv_o^3}{4\pi}k\iint C_1\sqrt{1-\mu^2}\cos\phi\,d\mu d\phi$$

so that if we assume as we evidently may

$$C_1=c_1\mu+c_2\sqrt{1-\mu^2}\sin\phi+c_3\sqrt{1-\mu^2}\cos\phi$$

We get

$$Q_x=\frac{k}{3}MNv_o^3\,c_1$$

$$Q_y=\frac{k}{3}MNv_o^3\,c_2$$

$$Q_z=\frac{k}{3}MNv_o^3\,c_3$$

Even in this most general form we can see that there will in general be a difference of pressure in different directions. For it is evident that the pressures in the three directions cannot be equal unless b_1 and b_2 both vanish, which will not in general be the case. Without a knowledge of the nature of the distribution of the velocities and numbers of molecules moving in the different directions, it would be impossible to calculate the values of b_1, b_2, b_3, b_4, and b_5, but I think we can see that they will in part at least vary as the square of the quantity of heat passing. This can be seen from the following considerations. No matter what the distribution of the velocities and number of molecules moving in the different directions may be, it is plain that terms occurring in the coefficients of $\sqrt{1-\mu^2}\sin\cdot\phi\ \sqrt{1-\mu^2}\cos\phi$ *i.e.* in the spherical harmonics of the 1st order in u and v will occur in the terms of the same order in $n\,v\ n\,v^2$ and $n\,v^3$ and that linearly, while these same terms will occur squared in the spherical harmonics of the 2nd order in $n\,v\ n\,v^2$, and $n\,v^3$. Hence we see that terms occurring linearly in the spherical harmonics of the 1st order in $n\,v^3$

will occur as squares in the spherical harmonic of the 2nd order in nv^2 so that b_1, b_2 will contain c_1 c_2 and c_3 in the second degree, *i.e.* will contain terms varying as the squares of the quantities of heat passing. It is also to be observed that terms occurring in the spherical harmonics of the 2nd order can never come into those of the 1st, except as products with terms belonging to spherical harmonics of the 3rd order so that a hypothetical distribution which gave correct values for the quantities of heat passing might very well be quite inadequate as a means of calculating the difference of pressure in different directions. This remark is of importance when we come to consider the results of Clausius' hypothesis and was suggested to me by Mr. Stoney in conversation.

As an example of what I am insisting upon, we may take two opposite extreme cases. First, the case of B_2 vanishing, and secondly the case of C_1 doing so. In the first case there would be a distribution of velocities and numbers such that though heat would be conducted across the layer nevertheless there would be no resultant inequality of stress, while in the 2nd case though no heat would be conducted yet there would be inequality of stresses. It seems, however, certain that neither of these extreme cases can exist as a permanent distribution in gases. Before calculating the values of these quantities upon particular hypothetical distributions, it may be well to see what they are in the simple case of two parallel planes each at a uniform temperature.

In this case it is evident from symmetry that if we take X normal to the planes we must have all our equations independent of ϕ as the effect is evidently symmetrical with regard to X. Then we get

$$b_2 = b_3 = b_4 = b_5 = o = c_2 = c_3$$

and there are no tangential forces while all the heat is transferred in the direction X and our pressures become—

$$P_{xx} = \frac{1}{3} MNv_o^2 \left(B_o + \frac{4}{15} b_1\right)$$

$$P_{yy} = P_{zz} = \frac{1}{3} MNv_o^2 \left(B_o - \frac{2}{15} b_1\right)$$

while the heat transferred is—

$$Q_x = \frac{k}{3} MNv_o^3 \, c_1$$

The excess of pressure in X over that in the normal directions is

$$P_{xx} - P_{yy} = \frac{2}{15} MNv_o^2 \, b_1 = \kappa$$

and this has been called Crookes's force.

That it depends wholly upon b_1, can be seen by the following simple method mentioned to me by Mr. Stoney :

Our expressions for P_{xx} and P_{yy} are

$$P_{xx} = M\Sigma nv^2\mu^2 \qquad P_{yy} = M\Sigma nv^2(1-\mu^2)\sin^2\phi$$

so that calling

$$n=\frac{N}{4\pi}I\,d\mu d\phi$$

when I depends upon the distribution of numbers only we can write the pressures

$$P_{xx}=\frac{MN}{4\pi}\iint Iv^2\mu^2 d\mu d\phi \qquad P_{yy}=\frac{MN}{4\pi}\iint Iv^2(1-\mu^2)\sin^2\phi d\mu d\phi$$

We can integrate them with respect to ϕ for we know that Iv^2 is independent of φ in the case we are considering—

$$\therefore\ P_{xx}=\frac{1}{2}MN\int Iv^2\mu^2 d\mu \qquad P_{yy}=\frac{1}{4}MN\int Iv^2(1-\mu^2)d\mu \qquad \therefore\ P_{xx}-P_{yy}=\kappa=\frac{3}{4}MN\int Iv^2(\mu^2-\tfrac{1}{3})d\mu$$

So that if Iv^2 be expanded in spherical harmonics, K depends only upon the spherical harmonic of the 2nd order. Similarly if Iv^3 be similarly expanded, it is easy to see that

$$Q_x=\frac{1}{2}MNk\int Iv^3\,\mu d\mu$$

can only depend upon the spherical harmonic of the 1st order in Iv^3.

If now we turn to particular hypotheses as to the character of the distribution of velocities and numbers the first that claims our attention is Clausius's. He starts from the assumption that the distribution of velocities among the molecules that have just encountered one another in any given layer, may be perfectly represented by supposing a small constant velocity in the direction of the transference of heat to be superposed upon a uniform distribution. This is the same as supposing that these velocities in various directions may be represented by the radii drawn to the surface of a sphere from a point slightly displaced from its centre. It is worthy of remark, in connexion with what I mentioned before with reference to the way the quantities in the various spherical harmonics are related to one another, that supposing the sphere to be an ellipsoid of even great ellipticity would not have affected his results, for it is easy to show that the ellipticity of an ellipsoid of revolution only enters into the spherical harmonics of the 2nd and higher orders so that it would not enter into the equation giving the quantity of heat except when multiplied by terms of at least the order of the quantity of heat. Thus even though the square of the ellipticity were of the order of the displacement from the centre of the point from which the radii representing the velocities are drawn, nevertheless that would at most only have introduced terms depending upon the product of these two, which would not have materially affected his results. Hence, we see that Clausius's success in calculating the quantity of heat conducted is no proof that his hypothesis is by any means a sufficient representation of the actual distribution for the purpose of calculating the resultant stresses, and that it is not, is proved by calculating what the Crookes' force would be upon his hypothesis. If this be done with the help of the quantities he gives in his note, (see Phil. Mag. vol. 23, 4th Ser., p. 526) we get—

$$K=\frac{1\cdot 8}{k^2}\cdot\frac{\rho_o T_o}{P_o}\cdot\frac{Q^2}{PT}$$

and the pressures deduced from this formula are very much smaller than those observed, so that it seems certain that the hypothetical distribution Clausius assumed is not at all adequate to represent the actual one. The pressures obtained by this formula are so insignificant that it is not worth while giving the details of the method by which it is deduced. That Clausius hypothesis is by no means adequate, can also be seen by the consideration that it is only after the Clausian laws for the conduction of heat have ceased to apply owing to the rarefaction of the gas that Crookes's force becomes remarkable as well as by considering what the distribution tends towards in this case, when the number of molecules is small compared with the distance between the heater and cooler, as has been done by Mr Stoney in his paper read before this Society at its last meeting. He shows, as is also pretty evident, that the distribution tends towards one which could be represented by two unopposing streams of molecules moving one towards the heater and the other towards the cooler. With such a distribution the laws of conduction of heat would of course differ somewhat from those deduced from Clausius' distribution.

I shall now calculate the result upon an arbitrarily assumed distribution, which, however, probably represents the actual one more nearly than Clausius'. I shall assume that the distribution of velocities can be represented by the formula—

$$
\begin{aligned}
v = v_o(1 &+ \alpha \cos\theta + \beta \sin\theta \sin\phi + \gamma \sin\theta \cos\phi \\
&+ a \cos\theta + b \sin^2\theta \sin^2\phi + c \sin^2\theta \cdot \cos^2\phi + 2f \cdot \sin^2\theta \sin\phi \cos\phi \\
&+ 2g \sin\theta \cdot \cos\theta \cdot \cos\phi + 2h \sin\theta \cdot \cos\theta \cdot \sin\phi
\end{aligned}
$$

where $\cos\theta = \mu$

This is equivalent to saying that it is represented very nearly by the radii drawn to the surface of a slightly elliptical ellipsoid from a point near its centre. I shall assume that $\alpha\ \beta\ \gamma\ a\ b\ c\ f\ g\ h$ are all quantities whose squares and products may be neglected. For the number of molecules moving in the given direction θ, ϕ I shall assume that it varies inversely as the velocity of the molecules moving in that direction so that $nv = Nv_o$. This evidently satisfies the condition $A_1 = o$. By these assumptions we obtain approximately $nv^2 = Nv_o \cdot v$ and $nv^3 = Nv_o \cdot v^2$ and hence

$$
nv^2 = Nv_o^2 \left\{ \begin{aligned}
&(1 + \alpha\mu + \beta\sqrt{1-\mu^2}\sin\phi + \gamma\sqrt{1-\mu^2}\cdot\cos\phi \\
&+ a\mu^2 + b(1-\mu^2)\sin^2\phi + c(1-\mu^2)\cdot\cos^2\phi \\
&+ 2f\sqrt{1-\mu^2}\sin\phi\ \cos\phi + 2g\,\mu\sqrt{1-\mu^2}\cdot\cos\phi + 2h\,\mu\sqrt{1-\mu^2}\cdot\sin\phi)
\end{aligned} \right\}
$$

or turning it into the form of a series of spherical harmonics

$$
nv^2 = N v_o^2 \left\{ \begin{aligned}
&1 + \tfrac{1}{3}(a+b+c) + (a - \overline{\tfrac{1}{2}b + c})(\mu^2 - \tfrac{1}{3}) + \tfrac{1}{2}(c-b)(1-\mu^2)\cos 2\phi \\
&+ 2f\sqrt{1-\mu^2}\cdot\sin\phi\cos\phi\ + 2g\,\mu\sqrt{1-\mu^2}\cdot\cos\phi + 2f\,\mu\sqrt{1-\mu^2}\cdot\sin\phi \\
&+ \alpha\mu + \beta\sqrt{1-\mu^2}\cdot\sin\phi + \gamma\sqrt{1-\mu^2}\cdot\cos\phi
\end{aligned} \right\}
$$

from which we see that

$$
b_1 = a - \frac{1}{2}(b+c) \qquad b_2 = \frac{1}{2}(c-b)
$$

$$
b_3 = 2f \qquad b_4 = 2g \qquad b_5 = 2h
$$

We may evidently include the $\frac{1}{3}(a+b+c)$ in the mean value of $Nv_o^!$ and take $B_o=1$ so that calling $MN=\rho$ the density of the gas our pressures become

$$P_{xx}=\frac{1}{3}\rho v_o^2\,[1+\frac{4}{15}(a-\frac{1}{2}(b+c)\}]$$

$$P_{yy}=\frac{1}{3}\rho v_o^2\,[1+\frac{4}{15}(b-\frac{1}{2}(c+a)\}]$$

$$P_{zz}=\frac{1}{3}\rho v_o^2\,[1+\frac{4}{15}(c-\frac{1}{2}(a+b)\}]$$

$$P_{yz}=\frac{2}{15}\rho v_o^2\cdot f=P_{zy}$$

$$P_{zx}=\frac{2}{15}\rho v_o^2\cdot g=P_{xz}$$

$$P_{xy}=\frac{2}{15}\rho v_o^2\cdot h=P_{yx}$$

Similarly from $nv^3=Nv_o\cdot v^2$ we can get

$$c=2a \qquad c^2=2\beta \qquad c^3=2\gamma$$

and hence

$$Q_x=\frac{2}{3}k\rho v_o^3\cdot a \qquad Q_y=\frac{2}{3}\cdot k\rho v_o^3\cdot\beta \qquad Q_z=\frac{2}{3}k\rho v_o^3\cdot\gamma$$

The normal pressures may also be put into the form

$$P_{xx}=\frac{1}{3}\rho v_o^2\cdot(1+\frac{1}{15}(a+b+c)+\frac{1}{5}(a-b-c)\}$$

$$P_{yy}=\frac{1}{3}\rho v_o^2\,(1+\frac{1}{15}(a+b+c)+\frac{1}{5}(b-c-a)\}$$

$$P_{zz}=\frac{1}{3}\rho v_o^2\,(1+\frac{1}{15}(a+b+c)+\frac{1}{5}(c-a-b)\}$$

So that the state of stress is a uniform pressure, and superposed upon it a system of pressures represented by the equations

$$p_{xx}=\frac{1}{3}\rho v_o^2\cdot\frac{1}{5}(a-b-c) \qquad p_{yz}=\frac{1}{3}\rho v_o^2\cdot\frac{2}{5}f=p_{zy}$$

$$p_{yy}=\frac{1}{3}\rho v_o^2\cdot\frac{1}{5}(b-c-a) \qquad p_{zx}=\frac{1}{3}\rho v_o^2\cdot\frac{2}{5}g=p_{xz}$$

$$p_{zz}=\frac{1}{3}\rho v_o^2\cdot\frac{1}{5}(c-a-b) \qquad p_{xy}=\frac{1}{3}\rho v_o^2\cdot\frac{2}{5}h=p_{yx}$$

Now it is remarkable that if $ax^2+by^2+cz+2yz+2gzx+2h\,xy=(lx+my+nz)^2$ we should have expressions for these additional unequal pressures, the same as Prof. Clerk Maxwell gives (See his "Electricity and Magnetism," vol. i., p. 129, and vol. ii., p. 256.) as expressing that state of stress in the ether which produces electrical phenomena. In order to make them identical all that is necessary is to put

$$X=l\sqrt{\frac{8\pi}{15}\rho v_o^2} \qquad Y=m\sqrt{\frac{8\pi}{15}\rho v_o^2} \qquad Z=n\sqrt{\frac{8\pi}{15}\rho v_o^2}$$

so that the resultant unequal pressures in the gas may be represented by a pressure $p=\frac{R^2}{8\pi}$ when $R^2=X^2+Y^2+Z^2$ in the direction given by

$$\mu : \sqrt{1-\mu^2}\sin\phi : \sqrt{1-\mu^2}\cos\phi :: X : Y : Z :: l : m : n$$

and an equal diminished pressure in every direction at right angles to this line. Double this pressure will be the Crookes' force, which is consequently in this case

$$K=\frac{1}{3}\rho v_o^2 \cdot \frac{1}{5}(l^2+m^2+n^2)$$

and it is in the direction whose direction cosines are proportional to $l : m : n$, so that if we put

$$l-\nu\mu \qquad m=\nu\sqrt{1-\mu'}\sin\phi \qquad n=\nu\sqrt{1-\mu'}\cos\phi$$

$$R=\frac{1}{15}\rho v_o^2 \, . \, \nu^2$$

The direction cosines of the line of transference of heat are evidently $\alpha : \beta : \gamma$ and so far there is no reason why these two lines should coincide although of course in most cases they probably differ but little in direction.

The only other distribution I shall consider is one suggested by Mr. Stoney's investigation (these Transactions, *ante* p. 39.) of the nature of the distribution of the velocities in the gas between two large parallel surfaces at uniform unequal temperatures. He has shown that it tends towards a distribution which would be represented by two streams of unpolarised gas moving in opposite directions across the layer. Now the actual distribution is never exactly this and possibly as he has mentioned departs in various degrees from it as you pass across the layer. If, however, we assume the distribution to be the same all the way across, and that consequently the mean temperature of each stream is that due to the surface it is leaving, we can calculate the resultant pressures.

If v_1 and v_2 be the mean velocities of the molecules in each stream respectively relatively to the centres of mass of the molecules, and if u_1 and u_2 be the velocities of the streams, *i.e.* of these centres of mass, and ρ_1 and ρ_2 their densities, the pressure upon a fixed plane normal to the direction of the streams is

$$P=\frac{1}{3}\rho_1 v_1^2+\frac{1}{3}\rho_2 v_2^2+\rho_1 u_1^2+\rho_2 u_2^2$$

while the pressure sideways is

$$p=\frac{1}{3}\rho_1 v_1^2+\frac{1}{3}\rho_2 v_2^2$$

so that the Crookes' pressure in this case is

$$K=P-p=\rho_1 u_1^2+\rho_2 u_2^2$$

In order that there be no accumulation of gas at either surface, we must evidently have

$$\rho_1 u_1=\rho_2 u_2$$

If V_1^2 and V_2^2 be the total mean squares of the velocities of agitation $V_1^2=v_1^2+u_1$, $V_2^2=v_2^2+u_2^2$ and the quantity of heat transferred is

$$Q=k(\rho_1 V_1^2 u_1 - \rho_2 V_2^2 u^2)$$

k being as before the coefficient by which the vis viva of translation has to be multiplied in order to get the total energy of the gas.

From these we easily obtain

$$K=\rho_1 u_1(u_1+u_2)$$
$$Q=k\rho_1 u_1(V_1^2 - V_2^2)$$
$$\therefore\ Q=kK\cdot\frac{V_1^2-V_2^2}{u_1+u_2}$$

We have besides $\rho_1+\rho_2=\rho$ where ρ is the density of the gas. Hence there are six equations between the six unknowns

$$\rho_1\ \rho_2\ v_1\ v_2\ u_1\ u_2$$

and in order to eliminate them and obtain an equation between K and Q it is necessary to make one further assumption. I assume then that $u_1=\lambda v_1$ and $u_2=\lambda v_2$ so that $V_1^2=(\lambda^2+1)u_1^2$ and $V_2^2=(\lambda^2+1)u_2^2$. I assume this because if the streams did not interfere with one another at all we should have

$$u_1^2=\frac{1}{6}V_1^2 \text{ so that if } \lambda^2+1=a^2 \text{ we should have } a^2=6 \text{ and } a=2\cdot5\ q.p.$$

Our equations then become

$$V_1 - V_2^2=a^2(u_1^2-u_2^2)$$
$$\therefore\ Q=kKa^2(u_1-u_2)$$

from these we can eliminate $u_1 u_2 \rho_1 \rho_2$ and putting $V_1^2-V_2^2=X^2$ we get

$$Q^4+4\frac{a^2k^2}{\rho}K^3Q^2-a^2k^4X^4\,.\,K^4=0.$$

Which is a quadratic for Q^2 or a biquadratic for K.

Solving for Q we get

$$Q=\frac{\kappa K\sqrt{a}}{\sqrt{\rho}}\left\{\sqrt{X^4\rho^2+4a^2K^2}-2aK\right\}^{\frac{1}{2}}$$

as evidently the other solutions are inadmissable.

From this we may get an approximate value for K in terms of Q for unless a be very large or the density or difference of temperature very small $X^2\rho$ is much greater than $2aK$. For instance if V_1 and V_2 correspond to a difference of 10°C

$$V_1=48500\sqrt{\frac{T_1}{273}} \qquad V_2=48500\sqrt{\frac{T_2}{273}}$$

and consequently

$$X^2=\frac{(48500)^2}{27\cdot3} \qquad \therefore\ X=9700$$

while $\rho=\frac{1}{800}$ for air at atmospheric pressure

$$\therefore\ X^2\rho=107600$$

and K would be large if it were 100, so that even if α were 50 still $2\alpha K$ would still be less than $\frac{1}{10}$th of $X^2\rho$ so that we may take approximately

$$Q = k\sqrt{\alpha}.KX$$

$$\therefore K = \frac{Q}{k\sqrt{\alpha}\cdot X}$$

From this we can calculate K; for $k=1\cdot6$ in most gases, and if $\alpha=2\cdot5$, $\sqrt{\alpha}=1\cdot5$ and $X=9700$ as above $\therefore k\sqrt{\alpha}X=22{,}310=2\times10^4$ *q.p.* Now at a distance of a fourth metre in air at atmospheric pressure, and with a difference of temperature of 10°C

$Q=10^6$ *q.p.* so that in this case

$\kappa=50$ *q.p.* which is within the limits of the quantities obtained in the case of the spheroidal drops on liquids.

That by this formula K varies nearly as Q and not as Q^2 is not to be wondered at because in the first place the formula only professes to represent an approximation to the true state of affairs, and in the second place it is only at distances and pressures at which the ordinary laws of conduction of heat cease to apply that it professes even approximately to represent it.

The whole of these investigations are unsatisfactory to this extent, that I have been unable, from a consideration of the molecular encounters themselves, to discover what is the actual distribution of velocities even in the simple case of two parallel surfaces. This is hardly to be wondered at for the problem is extremely complicated and evidently depends upon the undecided point in molecular physics, namely, the proportion of the molecules encountering in a given direction that are thrown off in the various other directions. We might very well assume with Maxwell that they are uniformly distributed in every direction after the encounter but even this does not simplify the question sufficiently to bring it within my present powers of solution.

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VOLUME I. (NEW SERIES).

VI.—*Notes on the Physical Appearance of the Planet Mars, as seen with the Three-foot Reflector at Parsonstown, during the Opposition of* 1877. By John L. E. Dreyer, M.A. With Plates I. and II. [Read February 18th, 1878.]

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WITH PLATES I. AND II.

[Read February 18th, 1878.]

During the opposition of Mars in the Autumn of 1877, the three-foot telescope was employed for the examination of the Planet's surface. The six-foot was also at first used, principally in the search for the newly discovered satellites, until it was found that the glare of the planet was too great to admit of the position of the outer one (the only one which could be perceived) being measured by the micrometer. The planet's low altitude at Parsonstown as compared with that at Washington will perhaps partly account for this.

On twenty nights the Planet was examined, but on fifteen only was the steadiness and quality of the image considered sufficient to admit of a trustworthy sketch being made. Twelve only of these have been considered worthy of being submitted for publication, the three others having been made under more unfavourable circumstances.

The following notes, referring to the several drawings which bear the corresponding numbers, were made at the time :—

PLATE I. Fig. 1. Sept. 7, $11^{h.}\ 50^{m.}$ Gr. M. T. Power 160 (generally used, sometimes a power of 215 was applied.)

„ 2. Sept. 8, $11^{h.}\ 0^{m.}$. Interrupted by clouds several times.

„ 3. Sept. 8, $11^{h.}\ 50^{m.}$ (time uncertain). Image very unsteady.

„ 4. Sept. 12, $11^{h.}\ 20^{m.}$ Through clouds; sketch unfinished, but showing all features correct.

„ 5. Sept. 15, $11^{h.}\ 35^{m.}$ Strong fog.

„ 6. Sept. 16, $10^{h.}\ 55^{m.}$ Definition excellent; details well seen.

PLATE II. „ 7. Sept. 17, $10^{h.}\ 55^{m.}$ Definition not good. Moonlight.

„ 8. Sept. 28, $11^{h.}\ 15^{m.}$ Sky a little hazy.

„ 9. Oct. 1, $10^{h.}\ 55^{m.}$ Sky a little hazy.

„ 10. Oct. 3. Time? About $11^{h.}\ 10^{m.}$ Image shaky.

„ 11. Oct. 8, $9^{h.}\ 40^{m.}$ Definition not quite satisfactory.

„ 12. Oct. 10, $9^{h.}\ 10^{m.}$ Definition not good ; details not satisfactorily seen.

The drawings have been compared by me with Mr. Proctor's chart; with the drawings made by Mr. Lockyer in 1862 (Mem. R. A. Soc. XXXII.) and with those of Kaiser (Annalen der Sternwarte in Leiden, Vol. III.)

"Lockyer Sea" was always seen of a very regular shape, slightly oval east and west. It appeared to be joined to the "De la Rue Sea" by an extremely faint and diffused band, but this was considered rather doubtful.

"Dawes' Sea," north of the above, seems only to be a thin streak running east and west.

"Bessel's Inlet" does not appear on any of the drawings, nor has it been seen by Lockyer or Kaiser. "Huggins' Inlet" must also have escaped my attention, if it really exists.

The "J. Herschel Strait" ends at "Dawes' Bay," east of which "Phillips' Island" is joined to "Dawes' Continent." I doubt greatly the existence of "Arago Strait."

"Dawes' Ocean" is considerably darker along the edges than in the middle. The region south of it was seen to be very different from the chart, and more in accordance with Kaiser's drawings. The bright spot on sketch No. 4 is probably "Kunowsky's Land."

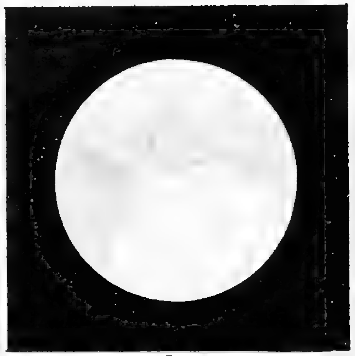
Plates I. and II. are, on the whole, fair representations of my drawings, except that the outlines are too sharp.

In fig. 3, Plate I., the triangle south of J. Herschel Strait is too sharp on the preceding side.

In fig. 4, Plate I., below the bright spot are two parallel streaks, the north one of which should be far more indistinct.

In fig. 8, Plate II., the streak north of Lockyer Sea should be extremely faint.

1.



Sept: 7, 11^{h} 50^{m} G.M.T.

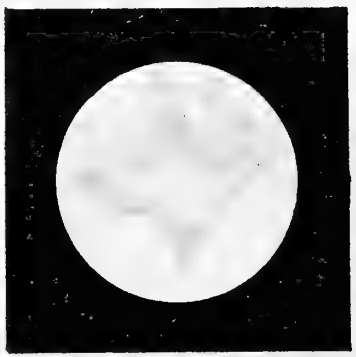
2.

Sept: 8, 11^{h} 0^{m}

3.

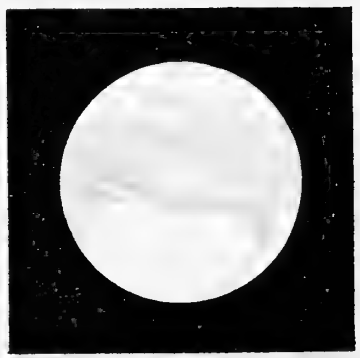
Sept: 8, 11^{h} 50^{m}?

4.



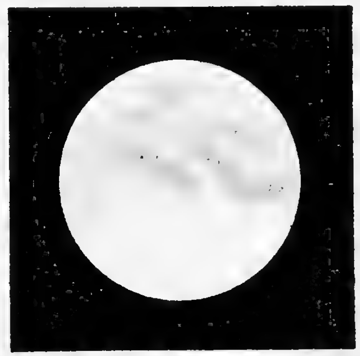
Sept: 12, 11^{h} 20^{m}
(unfinished)

5.



Sept. 15, 11^{h} 35^{m}

6.

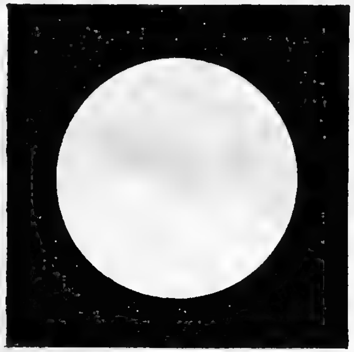


Sept. 16, 10^{h} 55^{m}

MARS. 1877.

J. L. E. Dreyer. del.

7.

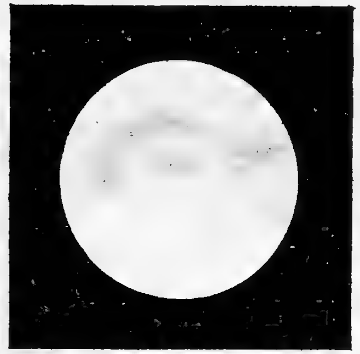


Sept. 17, $10^h 55^m$

8.

Sept. 28, $11^h 15^m$

9.

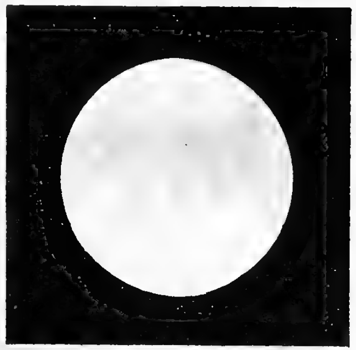


Oct. 1, $10^h 45^m$

10.

Oct. 3, $11^h 10^m$ (?)

11.



Oct. 8, $9^h 40^m$

12.

Oct. 10, $9^h 10^m$ ±

MARS. 1877.

J.L.E. Dreyer del.

TRANSACTIONS (NEW SERIES) VOLUME I.

(Already Published.)

[NOVEMBER, 1878.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (NEW SERIES).

VII.—PART I. *On the Nature and Origin of the Beds of Chert in the Upper Carboniferous Limestone of Ireland.* BY PROFESSOR EDWARD HULL, M.A., F.R.S., Director of the Geological Survey of Ireland. With Plate III.

PART II. *On the Chemical Composition of Chert and the Chemistry of the Process by which it is formed.* BY EDWARD T. HARDMAN, F.C.S. [Read 17th December, 1877.]

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VII.—Part I. ON THE NATURE AND ORIGIN OF THE BEDS OF CHERT IN THE UPPER CARBONIFEROUS LIMESTONE OF IRELAND. By Professor EDWARD HULL, M.A., F.R.S., Director of the Geological Survey of Ireland.

Part II. THE CHEMICAL COMPOSITION OF CHERT AND THE CHEMISTRY OF THE PROCESS BY WHICH IT IS FORMED. By EDWARD T. HARDMAN, F.C.S.

PLATE III.

[Read 17th December, 1877.]

PART I.

The Carboniferous Limestone underlies the greater part of the central plain of Ireland over which, however, it is generally concealed by beds of drift gravel, sand, and boulder clay which are spread over the lower grounds and the adjoining slopes of the hills. Along the south-east the limestone plain is bounded by the Granitic and Silurian rocks of the Dublin and Wicklow mountains; along the south and south-west by the ridges of Old Red Sandstone, which rise into the mountain ranges of Cork and Kerry; along the west by the Metamorphic and Upper Silurian rocks, which form the mountains of Connemara and Mayo; along the north-west by the Donegal Highlands, formed of similar strata; and along the north-east by the uplands of Westmeath, and the mountainous region of Slieve Gullion, Carlingford, and Mourne, which is deeply indented by Carlingford Lough, and the channel of the Newry canal. Thus in nearly every direction the central plain is bounded by mountain ranges; but at rare intervals the limestone forms the marginal coast-line of the country, as along the shores of Dundalk, Dublin, Galway, Sligo, and Donegal Bays.

Although generally occupying the plains, the limestone towards the north-west in the counties of Leitrim, Fermanagh and Sligo, rises into terraced hills of considerable elevation bounded by mural escarpments, and flanked by grassy or wooded slopes; while in the county Clare, in the Barony of Burren, the formation rises into scarped terraced hills, bare (except for scanty herbage) from the base to the summit, each successive bed cropping out, tier above tier, and ending off in mural scars; thus presenting features somewhat similar to those of the "Scar Limestone," of North Lancashire, Cumberland, and Yorkshire.

Perhaps the most remarkable physical features of the Carboniferous limestone districts of Ireland are the innumerable lakes with which its surface is studded, particularly over the central and northern portions of its range. In certain districts of Sligo, Fermanagh, Roscommon, Longford, Cavan, and Westmeath, lakes and

lakelets of every form and size stud the country in all directions, or form chains connected with each other by channels of sluggish rivers. In the upland districts of Sligo and Fermanagh these are replaced and represented by deep rock-bound hollows and swallow-holes, often connected with each other by underground watercourses opening out on the face of an escarpment, or giving birth to perennial fountains, which burst forth at the base of the cliffs and flow into the rivers and lakes of the plains. Some of them are equal in interest and extent to any which are found amongst the Derbyshire, Yorkshire, or Cheddar hills of the same formation, but the mass of water which flows beneath the surface from Lough Mask into the head of Lough Corrib, and bursts forth at Cong in several fountains of great size, is probably not equalled by any similar under-ground river in the British Isles.

In this connexion it may also be observed that not only the larger number of the lakes, but also of the bays and indentations of the coast-line, are formed where the Carboniferous Limestone prevails. Amongst these latter may be pointed out the Bays of Donegal, Sligo, Killala, Clew, Galway, Shannon Harbour, Tralee, Dingle, Kenmare, Cork Harbour, Dungarvan Harbour, Wexford, Dublin, and Dundalk. All these depressions along the coast occur where the Carboniferous Limestone either now exists, or did so originally before its place was occupied by the waters of the sea. As regards the lakes—nearly all those of special extent, such as Lough Erne, Lough Melvin, Lough Gill, Lough Conn, Lough Corrib, Lough Mask, Lough Ree, the Westmeath lakes, Lough Derg, and the Lakes of Killarney, rest upon floors of Carboniferous Limestone. Amongst these, the largest of the lakes of Ireland is not included; the age and mode of formation of Lough Neagh, being entirely exceptional.* However great the number of lakes at present in Ireland, it must have been at one time considerably greater, as it is well-known from the frequent occurrence of beds of shell-marl below the peat bogs, that the tracts occupied by the bogs themselves must have originally been sheets of water, and this at a time when the noble Megaceros was "the Monarch of the Glen."

On observing the close connexion which apparently exists between the distribution of the lakes in certain districts and the range of the Carboniferous Limestone it is impossible to doubt that the nature and composition of the rock is a main cause of the origin of such lakes themselves. Many of these lakes are true rock basins, such as Lough Erne, Lough Gill, Lough Mask, and Lough Corrib. Yet it is scarcely necessary in their cases to have recourse to the theory of glacial erosion in order to account for their formation. Without denying to this agency a certain effect in such cases, there can scarcely be a doubt that the most effectual agent in the formation of the Irish lakes has been water charged with carbonic acid, the solvent power of which has been aided by the flatness of the country and the sluggish character of the waters when flowing off in various directions towards the ocean.

* For a theory regarding the origin of Lough Neagh, see paper by E. T. Hardman, F.C.S., Journ. Roy. Geol. Soc. Ireland, vol. iv., part 3 (new series), p. 170.

Geological Structure.—The Carboniferous Series from the coal-measures downwards are generally divided as follows:—

		Irish Divisions.	British Representatives.
Stage	F.	Middle Coal-measures (Tyrone),	Middle Coal-measures.
„	E.	Lower do., or "Gannister Beds,"	Lower do. or Gannister Beds.
„	D.	Millstone Grit, and Carlow Flags,	Millstone Grit.
„	C.	Upper Shale series,	Yoredale Beds of Upper Limestone Shale.
„	B.	Upper Limestone,	Carboniferous or Mountain Limestone.
		Middle do. or "Calp Beds,"	
		Lower Limestone,	
„	A.	Lower Carboniferous Slate, Grit and Conglomerate,	Lower Limestone Shale or Tweedian Series.

From the above table it will be observed that the Carboniferous Series of England and Wales has its exact equivalents in Ireland, although the series in Ireland is less developed in its upper stages than in some parts of Britain, and there are slight differences in the mineral characters of the correlated strata. This subject I have dealt with more fully in another place.* I shall, therefore, content myself with some account of that member of the series with which we are immediately concerned on this occasion, viz.—the Carboniferous Limestone.

The great series of limestone strata included under this name rests (when the series is complete) on the Lower Carboniferous Slate of the south of Ireland into which, as the late Professor Jukes has suggested, the formation passes laterally as well as vertically towards the western shores of Kerry and Cork. In the north of Ireland, however, the basement beds of the Carboniferous system consist of grits, conglomerates, and shales with bands of earthy limestone (Mayo), the whole similar to the "Calciferous Sandstone Series" of Scotland, which is its exact representative in time. The Carboniferous Limestone itself is generally divisible into three members, as shown above, of which the central is the least persistent and characteristic. In the county Galway and the barony of Burren in the county Clare the central member is either absent, or so resembles the other two members as to be inseparable from them,† and the whole formation of 2,120 feet in thickness consists of beds of limestone with two cherty zones, the upper at 1,500 feet from the top of the formation, the lower about 400 feet from its base,‡ but in other parts of the country, especially towards the north and east, the three divisions are sufficiently distinct so as to present well-recognised physical features capable of

* This subject is treated in detail in a paper read before the Geological Society of London (25th April, 1877). "On the upper limit of the essentially marine beds of the Carboniferous System of the British Isles, &c." Quart. Journ. Geol. Soc., Nov. 1877.

† G. H. Kinahan. "Explanation" to sheet 124 of the Geol. Survey Maps, p. 10, 1876.

‡ G. H. Kinahan. "Explanation" to sheets 115 and 116 of the Maps of the Geological Survey of Ireland, p. 11. E. of Loughrea the Calp or Middle Division can be recognised.

being mapped out in detail. Beginning in the north-western districts we find the following series :—

Fermanagh, Sligo, &c.—Sections of the Carboniferous Limestone.

Yoredale Beds	Shales with Goniatites, &c. Yellow Sandstone.
Carboniferous Limestone (2,500 feet)	Upper Limestone with Chert. Middle or Calp Series. Lower Limestone.
Lower Carboniferous Sandstone, &c.	

The lower limestone occurs at Enniskillen, and along the banks of Lough Erne; it consists of bluish massive shelly and crinoidal limestone, with occasional bands of shale.

The middle or calp limestone consists of a thick series of dark earthy limestones and shales, the dark matter is carbonaceous, and is probably due to marine algæ; small bivalve shells are numerous, and likewise the trumpet-shaped coral, *Zaphrentis cylindrica.*

The upper limestone consists of massive coralline and crinoidal limestone, with beds of chert, which occur in greatest mass at the top, immediately below the Yoredale sandstone. Corals and crinoids are sometimes preserved in this chert. The upper limestone forms a range of hills, with scarped faces along the western shores of Lough Erne, also numerous isolated or prominent hills with scars or terraced sides, such as Benbulbin and Knock-na-Rea near Sligo, and Keshcorran on the borders of Leitrim. It is the most prominent member of the whole series in this part of Ireland, its great mural cliffs rising conspicuously above the slopes and valleys of the subordinate beds of the middle series, which being largely composed of soft shales and earthy limestones, seldom rise into the hilly ground, or give rise to marked features.

In the eastern districts of Ireland, the three divisions of the limestone are sufficiently characteristic, especially, on all sides of the Leinster and Tipperary coal basins—the following general section by Mr. J. O'Kelly of the Geological Survey of the beds, as they occur in the Queen's County, may be considered typical of the district.*

Section of the Carboniferous Limestone of the Queen's County.

Shale Series (Yoredale Beds).	Black and dark gray shales.
Upper Limestone.	Thick, regularly bedded, pale bluish crystalline limestone, in which layers and nodules of black and white chert are very common, particularly in the upper beds, the lower beds are magnesian to the west of Abbeyleix.
Calp or Middle Limestone.	Black and dark gray, impure flaggy limestones and shales.

* "Explanation" to sheet 127, of the maps of the Geological Survey. The section is somewhat abbreviated.

Lower Limestone.	Amorphous pale gray limestone, highly fossiliferous, resting on pale gray limestones, frequently oolitic; below these are regularly bedded dark gray crystalline limestones with thin beds of shale, and nodules of chert.
Lower Limestone Shale.	Thin grits, shales, and limestones—fossils abundant.*

The total thickness of the Carboniferous Limestone Series is about 2,500 feet.

In the south-western districts of Tipperary,† Limerick, Kerry and Cork, the principal masses of chert occur at the top of the limestone, immediately below the shales of the "Yoredale Series," and sometimes are so abundant as almost completely to replace the limestone itself.‡ The rock of Cashel with its ecclesiastical ruins and venerable round tower rising above the plain around, is a conspicuous example of cherty limestone.§

Although it is true that lenticular bands and nodules of chert or hornstone occur at intervals throughout the whole mass of the Carboniferous Limestone, yet it is unquestionable that the principal chert bearing zone, occurs at the top of the formation immediately under the upper shale series.|| In this position beds of considerable thickness occur around the base of the hilly country, which forms the coal basins of Castlecomer and Slievardagh. The late Professor Jukes and Mr. Kinahan in describing the upper limestone in Queen's County and Kildare, state that—"the chert layers are sometimes so frequent, that they make the rock nearly an entire mass of chert."¶ At the foot of the ridge west of Carlow, the limestone is completely replaced by masses of grayish chert in thin layers, and over thirty or forty feet in thickness. The same statement applies to the districts of Meath, Dublin and Kildare, where the upper limestone is generally dark, thin bedded, and flaggy, and in the upper part is generally associated with beds of chert.** It is, however, in the hilly districts of Sligo, Fermanagh and Leitrim, that the chert beds are most conspicuous, as they sometimes almost entirely replace the upper limestone, which (as already described) rises into escarpments with precipitous faces. A remarkable mass of this kind is the lofty rock called Benachlin, which rises abruptly above the wooded slopes of Florence Court, in the County Fermanagh, and is well known to palæontologists for the occurrence of specimens of *Pentremites* preserved in chert. Knock-na-Rea, the isolated hill which rises from the shore of Sligo Bay is another instance. Here the whole mass

* These are enumerated by Mr. Baily, Ibid. p. 10.

† "Explanation" to sheet 155, by J. O'Kelly of the Geological Survey of Ireland, pp. 13 and 16.

‡ "Explanation" to sheets 163, 174, &c. A very striking sketch of chert in the upper limestone N. of Newmarket, is given by Mr. Foot.

§ "Explanation" to sheet 155, p. 16.

|| According to Mr. Kinahan the "upper cherty zone" in the district bordering the Counties of Clare and Galway, occurs 1,500 feet below the top of the formation, but the whole of the "upper limestone" is more or less cherty. "Explanation" sheet 124, page 11.

¶ "Explanation" to sheet 128, of the Geological Survey Maps, p. 12.

** C. V. Du Noyer "Explanation" to sheet 101, p. 12.

of the "Upper Limestone" is highly coralline, and these organic forms together with the ossicles of crinoids are frequently preserved in solid chert. Amongst the corals, species of *Lithostrotion* are the most abundant.

Mode of Formation of Chert—Views of previous Observers.—Having thus endeavoured to show the geological position of the principal cherty zone in the Carboniferous Limestone of Ireland, we proceed to the consideration of the questions :—(1.) How was this material formed ? And (2.) when was it formed ? It was with the object of obtaining some satisfactory answer to these questions that I undertook the microscopical examination of specimens from various localities, receiving the ready aid of my colleague Mr. Hardman, F.C.S. in the chemical branch of the inquiry. Before entering on the questions above raised, I shall briefly notice the opinions of previous authors.

In attempting to enter upon a general historical review of the labours of other observers in this field, it will soon be admitted that the question of the origin and structure of Carboniferous chert, has not received sufficient attention from British, or other petrologists. In a valuable contribution to the literature of this subject by Professor T. Rupert Jones, F.R.S., he expresses the opinion that one form of "chert" is a pseudomorphous replacement by silica of detrital carbonate of lime, amongst which very many small organisms, pieces of shells, tests, and encrinital ossicles, either remain visible, or have left cavities which have been washed out ; in either case rendering the rock more opaque and coarse-grained than ordinary flint and hornstone.* Dr. W. K. Sullivan, observes,† that "in most limestones concretionary masses of silica occur. In the older rocks these concretions are termed *hornstone* or *chert*. In the chalk they are *flints* which according to Ehrenberg consist for the most part of the remains of infusoria. It is probable that some of the hornstones of the Carboniferous Limestone are also of organic origin, but that all are not so is proved by the partial conversion of fossil corals into hornstone, a fact which shows that the hornstone is due to a subsequent pseudomorphosis."

The views expressed by the two authorities above quoted are we believe fully borne out by microscopical and chemical examination, and represent very fairly the most recent opinions of British Geologists.

The frequent occurrence of beds of chert in the limestone formations of North America, has naturally attracted the notice of the naturalists of that Continent. Chert abounds in the limestones of the "Bird's Eye" and Black River divisions of the Trenton Group, (Lower Silurian), where it occurs in interrupted beds and masses of two or three inches in thickness. It also characterizes in an especial manner the limestones of the "Corniferous formation,"‡ (Lower Devonian), and occurs in the limestones of the Carboniferous system of Tennessee, Illinois, and

* "On Quartz, Chalcedony," &c. Proc. Geological Association, Vol. IV. No. 7.

† Jukes' Manual of Geology, 3 Edit. p. 60, 1872.

‡ Logan, Geology of Canada, p. 628.

other districts. Dr. T. Sterry Hunt observes that beds of chert, flint, hornstone, and buhrstone, have all apparently been deposited from aqueous solutions.* He also shows that silica replaces organic matter in fossils and refers to flint, chert, &c., as a proof of the large amount of silica in some waters.†

Mr. M. C. White's observations on the microscopical structure of hornstone from the Devonian and Silurian formations of New York, resulted in the discovery of numerous forms of *Desmidiæ,* also *Xanthidiæ* of rare forms, diatoms, spicules of sponges and fragments of gasteropods.‡ Similar results were obtained from observations on the nodules of hornstone from the Black River limestone, and that of the Carboniferous beds of Illinois, as shown by F. H. Bradley.§

The microscopical structure of true chert, (hornstein), does not appear to have been much followed up by continental Petrographers. Except, perhaps in a few places the beds of chert are not very largely distributed in the Carboniferous Limestone of Europe. In the black chert from this formation from the Plauenschen Grund, near Dresden, Ehrenberg discovered diatoms, &c. ("Mikrogeologie," XII. 37).

Those siliceous formations,—such as the berg mehl, tripoli, or polirschiefer, and saugschiefer, upon the origin of which by the direct agency of fossil infusoria, this distinguished naturalist has thrown so much light, do not come within the scope of this paper; for as we hope to be able to show, the rock here described under the term of "Chert," is due to a transmutation process, and not to any direct organic agency.

The observations of G. Bischof, although not directly bearing upon the formation of chert or hornstone in large masses, are interesting, and important in reference to the chemical process by which calcareous organisms, may be converted into siliceous. The existence of silicified corals in several localities has already been noticed, and Bischof points out the peculiar liability of such forms to silicification, owing to the innumerable pores by which the coral is perforated, through which waters charged with silica in solution, find their way and deposit the silex.‡‡ On the other hand, shells of bivalves, which are seldom found in a silicified form, being of more solid construction are less liable than corals to silicification, and usually are entirely dissolved away, leaving only the cast.|| He also observes, "The occurrence of quartz, chalcedony, hornstone, &c., in the form of calc spar, proves that silica is capable of displacing carbonate of lime."¶

It is doubtful whether the "hornstein" of German Petrographers is really the exact representative of our "chert." The description of the microscopic structure

* Logan, Geology of Canada, p. 574.

† Chem. and Geol. Essays, pp. 89 and 286, also "On the Silicification of Fossils," Canadian Naturalist, vol. I., 46.

‡ American Journal of Science, 1862, s. 383, also Annals and Mag. Nat. His. x. 160 (1862).

‡‡ See also PART II, on the chemical similarities of silica and carbon, by Mr. Hardman § *Ibid.*

|| Elements of Chemical and Physical Geology, Cavendish Edit. Vol. II., 489.

¶ *Ibid.* Vol. I., 198.

of hornstein by F. Zirkel, seems to be applicable to some form of quartzite rather than to the gelatinous form of silica, of which the chert here treated of is composed. He speaks of it as "Ein durchaus krystallinisches aggregat von eckigen und rundlischen Quartzkörnchen, von denen jedes wegen seiner abweichenden optischen orientirung im polarisirten Licht eine von der des Nachbarn verschiedene Farbe trägt."* The definition of "hornstein" given by A. von Lasaulx, is somewhat similar.† Of the Memoirs of British authors who have treated of the subject of the silicification of organic forms,‡ perhaps the elaborate and exhaustive description of the silicified fossil corals in the West Indies, by Dr. Duncan, F.R.S., throws more light on the question treated of in this paper, than that of any other author. The numerous and beautiful examples afforded by the corals of Miocene age of silicification in various stages, and in immediate proximity to others undergoing similar changes, throw much light on the causes and conditions under which transmutation has taken place in post-geological times. Dr. Duncan traces the completeness of the process in the case of many of the West Indian Corals, to the favourable conditions afforded by the intensity of heat and light for chemical reactions. Repudiating the view that the silicification of the corals has been due to volcanic outburst, (as some have supposed) he observes—"These facts rather tend to prove that the silicification of corals has been a slow process, which has had no other origin than in those chemical operations which are still in action, and that their greater or less intensity in certain favourable localities has produced siliceous fossils amongst those affected by the calcareous form of mineralization. Wherever a highly aerated sea containing silica in solution, acts on calcareous fossils at considerable depth and therefore under considerable pressure, there would appear to result a chemical transposition, and the presence of crystals of quartz, of homogeneous flint, and of hydrates of silica, is due to chemical influences which bear a relation to the geological changes in and about the reefs. In some cases not only the stony portions but the interspaces of the corals have been preserved in silica."§

Mineral conditions of the Chert.—Observations under the microscope tend to the conclusion that the chert occurs in a gelatinous or colloid, rather than in a crystalline, condition. This view is clearly sustained when a thin slice is examined under the polariscope. The vivid play of colours exhibited by quartz in a crystalline condition (as that of granite, porphyry, or rock-crystal) is well known. But in the case of the chert specimens examined, the effect was very different, the result of

* Die Mikroskop Beschaffenheit d.mineralien u. Gesteine, p. 108 (1873).

† Elem. de Petrographie, p. 156, 1875.

‡ Amongst them should be specially named Dr. Bowerbank, F.R.S., whose researches on the origin of flints and silicified zoophytes and sponges, are to be found in the Proc. Geol. Soc., Vol. III., 278 and 431; Trans. Geol. Soc., Vol. II., 181; and Brit. Assoc. Rep., 1856, part 2, p. 63, &c.; also Dr. Mantell, Wonders of Geology, 7 Edit., 1857 8.

§ "On the Fossil Corals of the West Indian Islands," Part III. Quart. Journ. Geol. Soc. Vol. XX. p. 373

rotating the analyzer being to change the light brown or gray colour of the specimen under parallel Nicol's prisms to dull or deep indigo when the prisms were crossed. The effect was very similar to that presented by chalk flint under similar circumstances.

The polariscope sometimes proved of assistance in bringing into view the organic forms, which, otherwise, were invisible or obscure. By its aid also small crystals, veins, and nests of calcite came into view. In rare instances calcite or crystalline quartz was found to have replaced the organic structure while the inclosing paste was in all cases gelatinous silica.

Appearance of the Organic Forms under the Microscope.—In general the visibility of the organic structures is solely due to their being more transparent than the inclosing siliceous paste. This latter appears as a clouded or mottled brown translucent substance in which the organic forms are set, and they being either clear or colourless can be distinguished from the inclosing paste. This suggests the idea that during the process of transmutation the conversion of the carbonate of lime did not take place simultaneously throughout. As the lime of fossil shells is generally in a crystalline condition, and the inclosing paste amorphous this latter would probably be more rapidly transmuted into silica than the former. Sometimes the forms are clearly and sharply defined, at other times they are shaded off, but in general there does not appear to be any definite wall between the paste and its inclosed organic form, the original shell or skeleton having altogether disappeared.*

Modes of Occurrence of Chert.—The modes of occurrence of chert, amongst the limestone rocks, are exceedingly varied and often indicate the pseudomorphic replacement of the original rock. When found in small masses it generally occurs in short lenticular beds with uneven surfaces abruptly terminating and lying in the planes of bedding. At other times the circumstances are entirely different, and the chert occurs in regular nodules of rounded fanciful forms, like flints in chalk, and planted transversely to the bedding of the rock; on the other hand I have never seen it assume the spongiform shapes of some chalk flints.

When it occurs in large masses the chert is banded or bedded in the direction of the planes of stratification, and is generally found in alternate beds with limestone, but sometimes almost entirely free from this rock. At all times the beds are more or less abruptly terminated or lenticular, although occupying the same general stratigraphical position. When the rock weathers, the chert bands or nodules stand out from the surface often in fantastic shapes, being less liable to decompose than the limestone which accompanies it. Some truthful sketches of these forms will be found in the Explanatory Memoirs of the Geological Survey of Ireland.

* Some of the slices which show foraminiferal structure resemble sections of the compact carboniferous limestone which, when sliced, is found to be full of foraminiferal shells; in each case the structure is preserved, but in the former the carbonate of lime is replaced by silica.

Description of Specimens.—The following is a brief account of the appearance of the microscopic sections of chert, which were very carefully prepared by Mr. Cuttell, of London:—

No. 1. From Upper Limestone, Ballymote, county Sligo.—Dark compact chert, without visible organic structure under the naked eye; under microscope shows wavy bands and obscure structures, some clearly organic, consisting of coralline and crinoidal fragments. A few veins of calcite are observable traversing the field of view.

No. 2. Specimen from same district as No. 1.—Brownish mottled slightly banded, organic forms in irregular layers; circular disks of crinoids, sometimes with dark central nuclei; obscure forms of foraminifers in section, coralline structures(?) and bivalves (brachiopods) with crystalline silica in interiors; numerous black grains, some angular octohedrons, probably crystals of pyrites, also minute black well-formed hexagons with central lucid points, probably sections of calcite with organic matter. The slice is traversed by veins of calcite of later date than the rock itself. (Mr. Hardman's analysis, No. 1.)

No. 3. Specimen from same district as No. 1.—Brownish mottled field of view, presenting numerous organic forms, many circular with dark centres (crinoidal stems) also bivalve shells (brachiopods) and coralline and foraminiferal forms; small crystals of calcite with dark linings and lucid centres are numerous; also, octohedral forms, slightly tinted, probably fluor spar.* In this specimen I also notice well formed black hexagons with lucid centres, of the nature of which I am in much doubt. Mr. Hardman suggests that they may be sections of sulphates of strontium and barium. (Analysis II.)

No. 4[a]. Specimen of black compact chert from the Upper Limestone of Knock-na-Rea, county Sligo.—The original calcareous rock has, apparently in this case, been highly cellular and fissured, so that it is replaced largely by mammilar chalcedonic silica lining the interiors of the cells, and the walls of the fissures; a few obscure forms of crinoid stems and foraminifera(?) may be made out in the more solid portions, much darkened by carbonaceous matter.

No. 4[b]. Specimen from same locality.—Dark chert containing corals (*Lithostrotion affine*) preserved in silica of a lighter colour. The analysis shows this to be a siliceous limestone, though having the appearance of chert. (Analysis III.)

No. 5. From Upper Limestone, Benachlan, Florence Court, county Fermanagh. —Black and compact, with bands of dark limestone alternating with the chert. Under the microscope the whole field shows organic structure; forms of foraminifera (*Valvulina*),† section of crinoidal stems, polyzoa, and curved fragments of bivalves can be discerned preserved in colourless translucent silica; amongst the other

* Mr. Hardman finds traces of fluoric acid in this specimen, hence the determination above arrived at.

† Determined by Professor Rupert Jones, F.R.S.

forms a deeply channelled section of a spine of an echinoderm (Archæocidaris ?) is apparent. (Analysis IV.)

No. 6. Dark chert; same locality as No. 5 but different bed.—Traces of organic structures obscure. Numerous small crystals of calcite inclosed in the silica and perfectly formed.

No. 7. Dark chert, compact, same locality as No. 5.—Organic forms numerous, but obscure and difficult of determination, probably chiefly foraminiferal. Contains 25·4 per cent. of carbonate of lime. (Analysis V.)

No. 8. Dark brown compact chert, same locality as No. 5.—The whole field shows organic forms more or less distinctly, consisting of crinoidal stems, polyzoa, foraminifera, and fragments of bivalves(?); external forms only preserved, interiors of clear structureless silica. The intermediate spaces of gelatinous silica sometimes contain minute granules grouped in twos and threes and joined at the margins. Their origin is uncertain.

No. 9. Dark compact calcareous chert interposed between bands of limestone containing fossils, Florence Court Park.—The whole field shows organic forms, amongst which sections of foraminifera and ossicles of crinoids may be distinguished. In general the forms are fragmental and arranged in parallel layers. The portion of the specimen analyzed by Mr. Hardman is a siliceous limestone. (Analysis VI.)

No. 10. White fossiliferous chert with laminated structure, from Upper Limestone of Bonnet's Rath, near Kilkenny.—Beds just below the Yoredale shales. Specimen consists of colourless amorphous paste inclosing numerous organic forms chiefly foraminiferal(?) which come into view with the aid of the polariscope There are also a few minute crystals of calcite inclosed. This specimen contains but very little lime. (Analysis VII.)

No. 11. Black compact chert with traces of fossils, from Bonnet's Rath quarry.—This specimen shows a wavy laminated structure, and with the aid of the polariscope faint organic structure throughout. Black grains of carbon(?) and crystals of calcite and silica are also inclosed. Proportion of lime slightly greater than in last. (Analysis VIII.)

No. 12. Compact black chert in irregular bands from Ballyfoyle, near Kilkenny. —Parts of beds fifty feet thick, just below the Yoredale shales; shows colourless paste mottled brown, with a few black grains, some cubical in form (probably pyrites); organic structure not apparent in this case. Well formed crystals of pyrites slightly decomposed, and of a slightly translucent copper colour along the edges; also diffused masses and grains of waxy yellow matter without structure, probably native sulphur. The proportion of lime excessively small. (Analysis IX.)

No. 13. Gray chert from bed somewhat below the last; shows grayish paste, full of obscure organic forms chiefly foraminiferal and molluscan (?). (Analysis X.)

No. 14. Dark chert with laminated structure, Kilmagar, county Kilkenny, just below the Yoredale shales; shows amorphous or laminated structure, but no appear-

ance of organic forms; there are also opaque cubical forms of doubtful origin. (Analysis XI.)

No. 15. Light gray chert, with crinoidal remains preserved in silica of a dark shade, beds nodular; shows a nearly colourless paste containing numerous circular forms, with sometimes a central darker point, in all probability sections of crinoidal stems; with polarized light, these are seen to be filled with silica sometimes showing a radiating structure, corresponding to the segments of crinoidal ossicles. (Analysis XII.)

Periods at which the Chert beds were formed.—Bands and nodules of chert occur (as we have seen) at various stages throughout the Carboniferous Limestone of Ireland, but chiefly in the uppermost beds, which (except in the county Clare) are very generally silicified. As regards the period of this last great silicification, Mr. Hardman and myself have arrived at the same opinion, that it took place during, and after, the formation of the limestone itself, and before that of the overlying Yoredale beds. It is to be observed in evidence of this view that the silicification does not extend into the joints, fissures, and faults, which were originated after the rock had been consolidated. The silicification has taken place in the mass of the limestone itself, either following rudely the planes of bedding, or forming wedge-shaped masses and large pockets. It is probable that immediately after its formation, the limestone, except where coralline, was in a soft and pasty condition. Microscopic sections show, that the more dense and compact portions are largely composed of foraminifera; and such beds probably existed in the form of "oceanic ooze," like that of the central Atlantic of the present day. The coralline and crinoidal beds, after their formation, would probably be open and porous. Thus, the whole calcareous mass to a variable depth would appear to have been somewhat accessible to the percolation of sea waters charged with silica and other compounds.

The sea-bed became shallower.—Throughout the period of the Carboniferous Limestone, the sea bottom was deep, the waters were usually clear and free from sediment, and land of a continental character producing rivers was distant from the central districts of Ireland. The limestone was built up by organic agency under such favourable conditions,* but the change from these clear water conditions to those of the succeeding period in which the Yoredale shales and mudstones were deposited, must have been due to terrestrial movements.

Amongst the results of these movements altering the physical geography of this part of the world, may be confidently stated the shallowing of the sea-bed over the limestone areas, also the production of slight discordancies in the stratification of the limestone to the overlying shale series. Mr. Hardman from numerous observations of the relations of these two formations around the borders of the Leinster Coal field, has come to the conclusion that the shales are locally uncon-

* Some of the most dense and unfossiliferous looking limestones, when examined microscopically, exhibit foraminiferal structures.

formable to the limestone, or rather the chert beds which represent it. The change from the one formation to the other is remarkably abrupt in that district, as it is also in the north-western districts. In other places it is less so, and there appear to be passage beds—but these are just the results we should expect from a general elevation of the sea-bed unaccompanied by any considerable displacements of the strata themselves. The shales and sandstones of the Yoredale series which overlie the limestone are themselves rarely silicified, nor are the fossils they contain converted into chert. All these considerations lead us to the conclusion that the silicification of the limestone took place before the deposition of the shales of the Yoredale series, and was accompanied by a general elevation of the sea-bed, which then became covered by shallower water than previously.

Manner of Silicification.—The *modus operandi* is the most difficult of all the questions we have proposed to ourselves in this inquiry; but we think the considerations already adduced lead us gradually to tolerably clear notions on the subject. We have also the observations of chemists and naturalists regarding similar transmutations in the mineral and animal kingdoms, particularly those of Professor Bischof in the one case, and of Professor Martin Duncan in the other.*

In the first place, the phenomena I have described go to show that the formation of the chert has resulted from the replacement of calcareous matter by silicious—because the microscopic sections indicate more or less distinctly the presence of organic forms of animals which from observation we know to secrete only carbonate of lime from the waters of the ocean—these are corals, crinoids, foraminifera, polyzoa and molluscs. In the second place, it has been shown that there is evidence that the calcareous material to be acted upon was placed in a condition highly favourable to the transmutation process, namely, that it was soft and porous, and was overspread by waters generally shallow. Professor Duncan has shown that it is under such conditions as these that the corals of the miocene period were converted into silicious material in the West Indian area, and he points out that the prevalence of heat and sunlight conduce to favour the transmuation process, inasmuch as they favour chemical reactions. Now such conditions as those I have suggested would result during the carboniferous period, as at the present day, in the production of warm waters pervading the central British areas; and if these waters happened to be charged with silica in solution, chemical reactions would at once be set up, favoured and promoted by tidal or other currents. As Bischof and other chemists have shown, either minerals or organic substances formed of carbonate of lime are always liable to replacement by silica when submerged in waters charged with this mineral; and we know also that the seas of the present day (and we may infer those of geological times) contain it in solution. As regards the actual chemical process, that is a discussion on which I have no intention of entering, preferring rather to leave the subject in the hands of my colleague, Mr. E. T. Hardman, F.C.S., who is well qualified to offer an opinion on the subject, and has appended the results of his investigation (see Part II.).

* Supra cit.

GENERAL CONCLUSIONS.

(1.) That carbonate limestone chert is essentially a pseudomorphic rock consisting of gelatinous silica replacing limestone of organic origin chiefly foraminiferal, crinoidal, and coralline.

(2.) That this replacement occurred locally and at intervals throughout the period, and during the formation of the carboniferous limestone of Ireland, but in a special and extensive degree at the close of the limestone period, and before the overlying Yoredale shales were deposited.

(3.) That this replacement occurred under the waters of the sea itself while the limestone was in a more or less plastic condition, admitting the free percolation of water, holding silica in solution.

(4.) That as regards the *modus operandi*, the phenomena may be accounted for upon the principles of chemical transmutation explained by Bischof and other physicists, and illustrated by the examples of the silicification of miocene coral beds of the West Indies, as described by Professor Martin Duncan. At intervals, during the formation of the limestone, the limestone was replaced by silica in solution. This process took place on a large scale at the close of the limestone period. From some cause probably connected with the elevation of the sea-bed,* the waters of the sea appear to have been largely charged with silica in solution, while the chemical process was accelerated by the warm surface waters of a shallow sea, and thus the transmutation process was more effectually brought about than previously.

(5.) It does not appear that the case of silicious sea bottoms, such as that of the great depths discovered by the soundings of the "Challenger" in the Southern Ocean, affords an example of the phenomena here described—the sea bottoms referred to being directly due to animal organisms secreting silica, such as Diatomaceæ, Polycystineæ, and the spiculæ or skeletons of sponges. The silicious material here described can only be considered as a secondary product due to the replacement of lime carbonate by silica.

EXPLANATIONS OF PHOTOGRAPHIC SECTIONS OF CHERT, PLATE III.

Fig. 1. Coralline chert, from Knock-na-Rea, County Sligo, described No. 4, p. 48, mag. 3 diams.

„ 2. Black compact chert, from Benachlan, Florence Court, County Fermanagh, described No. 5, p. 48, mag. about 15 diams.

„ 3. Dark compact chert, from Ballymote, County Sligo, described No. 1, p. 48, mag. about 10 diams.

„ 4. Brownish mottled and band chert, from Ballymote, County Sligo, described No. 2, p. 48, mag. about 10 diams.

„ 5. Black compact chert, from Knocknarea, County Sligo, described No. 4, p. 48, mag. about 10 diams.

„ 6. Dark compact calcareous chert from Florence Court Park, County Fermanagh, described No. 9, p. 49. This section exhibits the structure of the original limestone, in a transitional condition between limestone and chert, as shown by Mr. Hardman's analysis (No. IX), mag. about 19 diams.

* See Mr. Hardman's remarks.

Fig 1

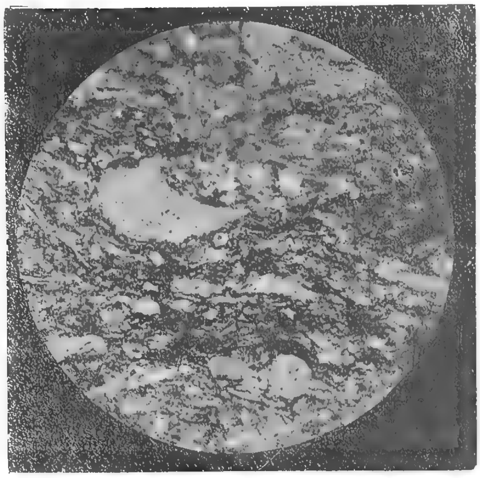

Fig 2

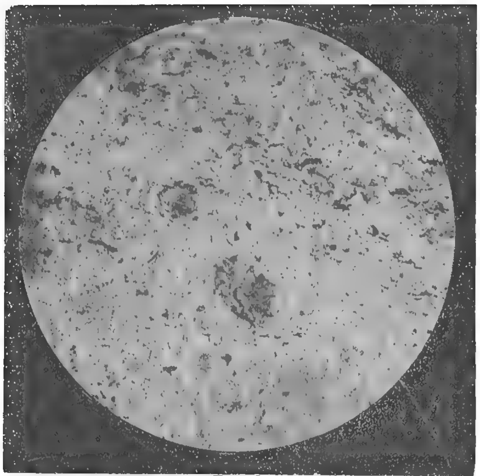

Fig 3

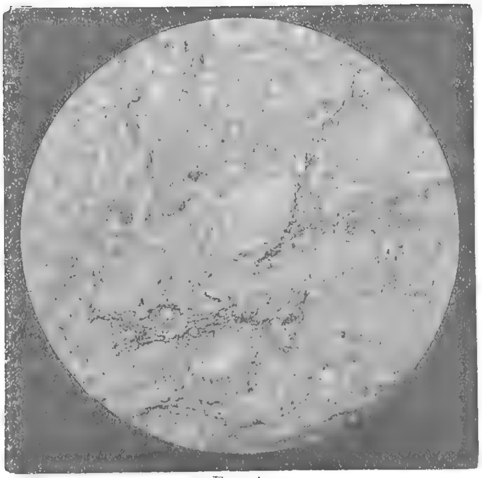

Fig 4

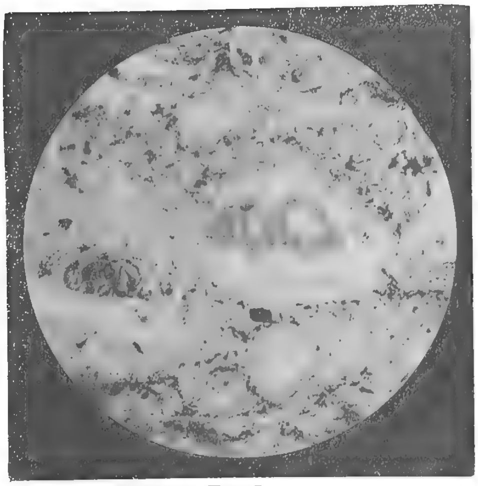

Fig 5.

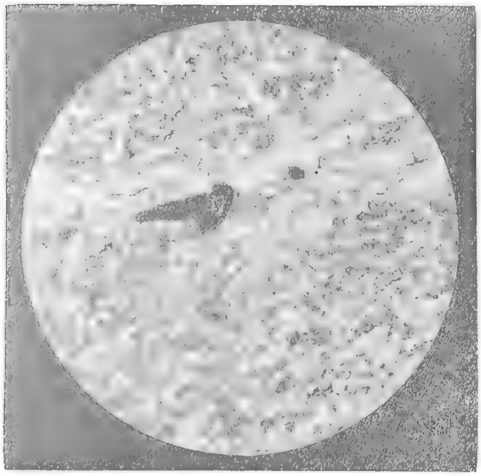

Fig 6.

Millard & Robinson Photo.

PART II.

THE CHEMICAL COMPOSITION OF CHERT, AND THE CHEMISTRY OF THE PROCESS BY WHICH IT IS FORMED. BY EDWARD T. HARDMAN, F.C.S.

The following twelve analyses of specimens from amongst those examined microscopically by Professor Hull, throw much light upon the origin of Chert. It will be observed that the composition varies from that of a siliceous limestone to that of an almost wholly siliceous rock. I have been unable to find any published analysis of this mineral, except one given by Dana of a gray chalcedonic hornstone from Marienbad,* the composition of which resembles that of some of the more siliceous varieties I have examined; but neither the formation in which it is found, nor the mode of its occurrence are mentioned—this and the statement by Cotta † and others that Chert consists mainly of silica, with but traces of impurities in the shape of other constituents is about all that is to be found in the mineralogical text-books with regard to it. Dana says, "Chert is a siliceous stone containing some lime;" while Gmelin classes hornstone amongst the crystalline varieties of Chert.

The numbering of the specimens corresponds with that used in the section on the microscopic examination. It should be mentioned that many of the specimens contained strings and veins of calcite of later origin—care was taken to select portions for analysis perfectly free from these. The carbonate of lime noted below in the analyses is undoubtedly an original constituent.

The analyses were conducted as follows:—Two analyses of each specimen were made. (*a*) The powdered chert was boiled with hydrochloric acid and allowed to remain in it one night. The solution gave the soluble silica and the carbonates, together with some iron oxide (chiefly protoxide) and alumina. (*b*) A fresh portion of the chert, or in some cases the residue from (*a*) was fused with the alkaline carbonates, giving the insoluble silica, with alumina, ferric oxide, and sometimes lime and magnesia; column (*b*) in the tabulated analysis represents in each case the analysis of the insoluble residue of (*a*) minus the organic matter, &c.‡ The third column gives the total analysis of the specimen made up from (*a*) and (*b*).

* System of Mineralogy (1873), p. 195.

† Rocks classified and described. See also Dana's Manual of Mineralogy. Nicol's Elem. of Mineralogy. Watt's Chem. Dict. Ure's Dict. Sci. and Art. Gmelin's Hand-book of Chemistry, &c.

‡ These were determined in other portions of the rock, but for convenience I have placed them in column (*a*).

Analyses of the Specimens.

No. 2. A dark chert, very hard but brittle; cannot be scratched with a knife; effervesces freely with acid.

Analysis I.

	a.	b.	Total Analysis.
Silica ($Si\ O_2$) (Insoluble),	–	79·82	79·82
Silica ($Si\ O_2$) (Soluble),	1·00	–	1·00
Fe_2O_3,	–	0·79	0·79
Al_2O_3,	1·05	1·94	2·99
FeO,	0·20	2·00	2·20
*CaO,	–	0·81	0·81
MgO,	–	trace	trace
$CaCO_3$,	12·00	–	12·00
$MgCO_3$,	trace	–	trace
$SrCO_3$,	traces	–	"
Fl,	"	–	"
Na_2O,	"	–	"
K_2O,	"	–	"
Water and organic matter,	0·20	–	0·20
Insoluble residue,	85·43	–	–
	99·81	85·36	99·81

Specific gravity not determined.

With Smithson's modification of Berzelius' method very appreciable traces of Fluorine became apparent, but not enough to estimate.

No. 3. Hard dark chert, cannot be scratched; but effervesces freely with acid.

Analysis II.

	a.	b.	Total Analysis
SiO_2 (Insoluble),	–	80·45	80·45
SiO_2 (Soluble),	trace	–	trace
Fe_2O_3, Al_2O_3,	0·55	1·73	2·28
FeO,	traces	–	trace
CaO,	–	0·53	0·53
$SrSO_4 + BaSO_4$,	0·43	–	0·43
$CaCO_3$,	14·62	–	14·62
$MgCO_3$,	trace	–	trace
Na_2O,	"	–	"
Fl. very distinct traces,	"	–	"
Water and organic matter	1·60	–	1·60
Insoluble residue	82·75	–	–
	99·95	82·71	99·91

Specific gravity, 2·625.†

In this specimen also there are distinct traces of Fluorine, confirming Professor Hull's determinations of fluor-spar. Strontium and Barium are also present, doubtless combined with the small portion of sulphuric acid also observed as above. It has occurred to me that the hexagonal forms which Mr. Hull has noticed (*ante*), may

* The lime and magnesia found in the insoluble residue in this and other specimens, are doubtless combined as silicates.

† The specific gravity of most of these specimens was kindly determined for me by Mr. W. Plunkett. F.C.S., Royal College of Science, Dublin.

be sections of these sulphates; the common crystalline form of which cut vertically through the brachydiagonal would show a six-sided figure.*

No. 4. Black chert with corals highly silicified, extremely hard; cannot be scratched, does not effervesce with acids, parts of the corals replaced by crystalline silica.

ANALYSIS III.

	a.	*b.*	Total Analysis.
SiO_2 (insoluble),	–	91·645	91·645
SiO_2 (soluble),	1·500	–	1·500
Fe_2O_3, Al_2O_3,	0·650	0·740	1·390
CaO,	–	0·665	0·665
MgO,	–	0·090	0·090
$CaCO_3$,	3·150	–	3·150
$MgCO_3$,	0·500	–	0·500
Water and organic matter,	0·800	–	0·800
Insoluble residue,	930·50	–	–
	99·650	93·140	99·740

Specific gravity, 2·769.

No. 5. A dark siliceous limestone passing into Black Chert. The limestone scratches easily and effervesces freely, but these characteristics diminish as the cherty parts are reached. The knife makes no impression on these, but they effervesce somewhat freely.

ANALYSIS IV.

	a	*b.*	Total Analysis.
SiO_2 (insoluble),	–	8·40	8·40
Fe_2O_3, Al_2O_3,	1·70	0·50	2·20
FeO,	0·70	–	0·70
$CaCO_3$,	82·50	–	82·50
$MgCO_3$,	1·00	–	1·00
Water, organic matter, and sulphur,	4·85	–	4·85
Insoluble residue,	8.99	–	–
	99·74	8·90	99·65

Specific gravity, 2·649.

That the microscopic characters of this and specimen No. 9, so much resemble those of the true chert, is a point in favour of the pseudomorphic character of the latter.

No. 7. Dark chert, extremely hard and dense. In ordinary condition cannot be scratched; effervesces rather freely with acid, and the places touched with acid can be afterwards scratched. Gives off a very fetid odour (sulphuretted hydrogen from the remaining organic matter, or probably due in part to the presence of sulphide of calcium) on being broken up.

* M. Dieulafait finds that strontium is widely and appreciably diffused in sea and spring waters; also in marine rocks, minerals, and fossils. (Comptes Rendu, lxxxiv. 1303.)

Analysis V.

	a.	b.	Total Analysis.
SiO_2 (insoluble),	–	65·15	65·15
SiO_2 (soluble)	–	–	traces
Al_2O_3,	1·50	2·05	3·55
Fe_2O,	–	0·45	0·45
FeO,	0·50	–	0·50
CaO,	–	0·95	0·95
MgO,	–	trace	trace
$CaCO_3$,	25·40	–	25·40
$MgCO_3$,	0·50	–	0·50
Organic matter, water, and sulphur,	3.50	–	3·50
Insoluble residue,	68·28	–	–
	99·68	68·60	100·00

Specific gravity, 2·626.

Although to all appearance a true chert in outward character, the analysis shows this to be strictly a very calcareous chert. It is clearly in the transition state. Such specimens might be termed *pseudo-cherts.*

No. 9. A dark highly siliceous limestone. Hard and extremely tough; scratches easily, and effervesces freely. It passes in places into true chert, a few strings of which are visible. Like Nos. 5 and 7, this specimen gives off a strong odour of sulphuretted hydrogen on being crushed.

Analysis VI.

	a.	b.	Total Analysis.
SiO_2 (insoluble),	–	16·00	16·00
SiO_2 (soluble),	traces	–	traces
Fe_2O,	–	trace	trace
Al_2O_3,	0·50	0·70	1·20
FeO,	0·35	0·75	1·10
CaO,	–	1·50	1·50
MgO,	–	trace	trace
$CaCO_3$,	73·22	–	73·22
$MgCO_3$,	2·75	–	2·75
Water 1·00, org. matt. 1·48, and sulph. 2·30,	4·78	–	4·78
Insoluble residue,	18·60	–	–
	100·20	18·95	100·55

Specific gravity, 2·647.

No. 10. White chert passing into light gray siliceous limestone; extremely hard and brittle, being much jointed. Cannot be scratched; effervesces but slightly. This specimen exhibits incipient rhombohedral cleavage, modified by the peculiar splintery fracture of chert.

Analysis VII.

	a.	b.	Total Analysis.
SiO_2 (insoluble), ...	–	93.20	93.20
SiO_2 (soluble), in HCl, . .	trace	–	trace
Fe_2O_3, Al_2O_3, ...	1·15	0·80	1·95
FeO, ...	0·10	–	0·10
CaO, ...	–	0·70	0·70
MgO, ...	–	trace	trace
$CaCO_3$, ...	2·90	–	2·90
$MgCO_3$, ...	0·20	–	0·20
Water and loss, . . .	0·95	–	0·95
Insoluble residue, ...	94·65	–	–
	99·45	94·70	100·00

SiO_2, soluble in caustic potash, 0·45 per cent.
Specific gravity, 2·750.

In the analysis of this specimen a curious circumstance was noticed. The fused mass dissolved readily in water, but the addition of hydrochloric acid failed to precipitate the silica in the gelatinous condition as is usual. The liquid remaining perfectly clear until evaporated almost to dryness. The same occurred with No. 15 (see *post*).

No. 11. An extremely hard black chert, cannot be scratched, effervesces but very slightly with acid; incipient rhombohedral cleavage like the last, so that it is rather easily broken up, the cleavage planes are coated with more recent calc-spar; but the portions taken for analysis were carefully selected, so as to be free from this.

Analysis VIII.

	a.	b.	Total Analysis.
SiO_2 (insoluble), ...	–	93·10	93·10
SiO_2 (soluble)	trace	–	trace
Fe_2O_3 Al_2O_3	0·40	0·50	0·90
FeS, ...	trace	–	trace
CaO, ...	–	0·30	0·30
MgO, ...	–	trace	trace
$CaCO_3$, ...	3·75	–	3.75
$MgCO_3$, ...	trace	–	–
Water and organic matter, &c., .	1·95	–	1·95
Insoluble residue, ...	93·90	–	–
	100·00	93·90	100·00

Specific gravity, 2·652.

No. 12. Bedded chert. Dark, compact, extremely hard chert—impossible to scratch—hardly any effervescence with acid even when powdered. Tested according to Plattner's and Von Kobell's methods, gives evident traces of the presence of a metallic sulphide, doubtless iron-pyrites, which Mr. Hull has observed in the microscopic section.

ANALYSIS IX.

	a.	b	Total Analysis.
SiO_2 (insoluble),	–	95·50	95·50
SiO_2 (soluble),	trace	–	trace
Fe_2O_3, Al_2O_3,	0·41	3·15	3·56
CaO,	–	trace	–
$CaCO_3$,	0·66	–	0·66
FeS,	trace	–	trace
Water and organic matter,	0·25	–	0·25
Insoluble residue,	98·55	–	–
	99·87	98·65	99·97

Specific gravity, 2·628.

The above is one of the purest specimens of chert I have examined, although both from its appearance and its position lying close beneath the Yoredale Shales, I was prepared to find a considerable quantity of silicates of alumina and iron in it.

No. 13. Light, gray chert from nodules in the limestone, just below the last—very hard, effervesces slightly with acid.

ANALYSIS X.

	a.	b.	Total Analysis.
SiO_2 (insoluble),	–	85·60	85·60
SiO (soluble in HCl),	1·22	–	1·22
SiO_2 (soluble in KHO),	–	0·95	0·95
Fe_2O_3, Al_2O_3,	0·73	2·44	3·17
FeO,	0·10	–	0·10
CaO,	–	1·09	1·09
MgO,	–	2·20	2·20
$CaCO_3$,	4·40	–	4·40
$MgCO_3$,	trace	–	trace
Na_2O,	trace	–	trace
Water and organic matter,	1·12	–	1·12
Insoluble residue,	92·31	–	–
	99·88	92·28	99.85

Specific gravity, 2·566.

The small quantity of silica dissolved by a strong solution of potash, is probably some hydrated silica, the result of alteration.

No. 14. Bedded chert from the same horizon as No. 12, and possessing much the same characteristics and appearance.

Analysis XI.

	a.	b.	Total Analysis.
SiO_2 (insoluble),	–	95·50	95·50
SiO_2 (soluble),	trace	–	–
Fe_2O_3,	–	0·10	0·10
Al_2O_3,	–	1·95	1·95
FeO,	–	0·15	0·15
MgO,	–	trace	trace
$CaCO_3$,	0·87	–	0·87
$CaSO_4$,	trace	–	trace
Na_2O,	trace	–	trace
Water and organic matter,	1·43	–	1·43
Insoluble residue,	97·60	–	–
	99·90	97·70	100·00

Specific gravity, 2·614.

It is curious that the chemical composition of this specimen is almost identical with that of No. 12, which is taken from the same horizon, but at a distance of some miles.*

No. 15. A very hard white chert, very fossiliferous, passing into a gray siliceous limestone—effervesces slightly.

Analysis XII.

	a.	b.	Total Analysis.
SiO_2 (insoluble),	–	90·90	90·90
SiO_2 (soluble in HCl),	trace	–	trace
Fe_2O_3,	0·40	0·30	0·70
Al_2O_3,	0·70	0·65	1·35
FeO,	0·30	–	0·30
CaO,	–	0·50	0·50
MgO,	–	trace	trace
$CaCO_3$,	5·90	–	5·90
$MgCO_3$,	0·25	–	0·25
Water,	0·35	–	0·35
Insoluble residue,	92·15	–	–
	100·05	92·35	100·25

SiO_2 soluble in caustic potash, 0·50 per cent.
Specific gravity, 2·698.

The chert presented the same anomalous behaviour already noticed in No. 10. That is, that after having been fused with the alkaline carbonates and dissolved in water, no silica was precipitated on addition of hydrochloric acid, and the solution remained perfectly clear, until evaporated down nearly to dryness. In all the other analysis the silica was immediately thrown down on the addition of acid, and I am unable to account for these exceptional cases, otherwise than on the supposition that the cherts must have undergone some degree of alteration. What makes this case more remarkable is, that boiled with a strong solution of caustic potash, these specimens yielded hardly any silica as may be seen from the analysis.

In this connexion I should note the fact, that none of the cherts yield more than

* These cherts are also on the same horizon as that near Carlow, which is the Irish locality for Lydian-stone given by Greg and Lettsom in the Manual of Mineralogy of Great Britain and Ireland, p. 91.

traces of silica when treated with a strong solution of caustic potash, even after long continued boilings. As there can be no doubt that the silica of chert is in the amorphous condition, Fuch's statement* that the amorphous silica of chalcedony and flint can be removed by a solution of caustic potash must be a mistaken one, especially as he refers opal to the anhydrous amorphous form. I think it is much more likely to be the hydrated forms of silica which are so affected, and this has been lately shown to be the case by C. Friedel, in his paper on the alteration of flints.†

The following points will be apparent from the foregoing analyses.

1. That chert has no definite chemical composition, the amount of silica in specimens (which present but little external differences) varying from 65·15 per cent. to as much as 95·50 per cent., and it is not unlikely that a larger series of analyses would show a complete transition from ordinary limestone up to the most siliceous variety of chert.

2. The silica is in the anhydrous condition, and is practically uncombined with bases—the amount of lime, iron, &c., combined as silicates being extremely small, and the principal variation in compositions is due to the residue of carbonate of lime remaining from the original limestone.

3. Taken in connexion with the microscopic examination, the analyses go to show that the formation of chert can only be accounted for by a process of pseudomorphism from limestone. The varying proportions of the silica and the carbonate of lime—together with the presence of organisms whose shells, originally calcareous now silicified, are visible in some of the most highly siliceous specimens—prove this.

Process by which the change was effected.—The above points being true, it only remains to show how the change could have taken place. The process of pseudomorphism by substitution or *replacement* might be defined chemically, as that by which *any liquid holding mineral matter in solution deposits a less soluble mineral in order to take up a portion of a mineral which it can more easily retain in solution.* There may be a few exceptions to this, but I think it will be found to hold good in most cases, and that the pseudomorph is almost invariably a more insoluble body than that which it replaces. In the many experiments made by Bischof with various solutions on minerals, the results are altogether in accordance with this view, and it is thus easy to account for the occurrence of chert. Supposing that the ocean in which the limestone was being formed contained an unusually large per-centage of silica (which would mean, however, actually a very trifling proportion), it is but natural to suppose that the water would elect to dissolve small portions of the more easily soluble carbonate of lime, and in their place to deposit equivalent portions of the less soluble silica in the gelatinous state.

That this would go on at the bottom of the sea there could be no reason to doubt, and contemporaneously with the accumulation of the limestone itself, and another circumstance would assist in the process—the gradual decay of the animal matter

* L. Gmelin's Hand-book of Chemistry, Cavendish Soc. Ed., Vol. III., 354.

† "On certain alterations of Agates and Flints," Comptes Rendus lxxxi 979; also Journ. Chem. Soc. Lond. Vol. I. N.S. p. 526.

of dead organisms. This would give rise to a variety of soluble matter, which would be taken up by the sea water; and here again insoluble silica would be deposited. And another point must be noted here, not only pseudomorphism, but something of the nature of isomorphism may come into play. It is well known that the compounds of carbon and of silicium present great similarities. Everyone is acquainted with the fact that both have three distinct modifications, the crystalline, the graphitoidal, and the amorphous; but not only this: it has been shown that the silicium compounds are built up exactly like the carbon ones, and that the chemistry of silicium is similar in every respect to what is known as organic chemistry, or "the chemistry of Carbon." Nothing is more likely therefore, than that the relation between them should help to determine the substitution of the silicic anhydride for the carbonic anhydride given off during organic decomposition.

That silica readily replaces organic matter is well proven. It is only necessary to refer to the well known wood opals—the silicified woods which are met with in the Tertiary deposits of many places in the world. In New Zealand; the Rocky Mountains; and at home in the neighbourhood of Lough Neagh, Ireland. In these specimens the organic tissue has been replaced bit by bit by silica.* It might also be inferred that it rather exerts an elective affinity in favour of organic matter, for in many limestones the corals and more prominent fossils are almost completely silicified, while the limestone paste has been but little affected. I have lately examined many of the limestones in the neighbourhood of Kilkenny, especially that of the marble quarries, which is extremely fossiliferous, and I find the fossils to a greater or less extent silicified, whilst the limestone is comparatively unaffected. Thus it will be seen that the silica could replace both the inorganic and organic matter of such a marine deposit as limestone.

Although I throw out the above suggestion with regard to the result of molecular affinity, the point as to difference of solubility is perhaps more vital to our question, for most of the silicification is probably due to this cause. As an illustration, I may mention, that calcite often replaces organic matter for this reason. Daubrée † has described the petrifaction, in part, of the wooden piles sunk by the Romans in the foundations of structures at Bourbonne-les-Bains, the petrifying material being calcite. Daubrée remarks that no calcareous incrustations are found in proximity to the mineralized wood, so that the vegetable tissue must by a kind of selection have drawn the calcium carbonate to itself and concentrated it in its cells. The likelihood is that the water charged with calcium carbonate met with nothing more soluble in the surrounding soil, and therefore, passed through it without depositing any calcareous matter, but those portions of water which came in contact with the decaying organic matter yielded up their carbonate of lime and removed the more

* "The process of petrifaction of organic bodies is in reality a species of pseudomorphic formation." Elem. of Mineral., J. Nicol, F.R.S.E., &c. (1873), p. 53. See also Dana's Manual of Min. (1867), p. 54.

† Mineralization of organic remains. A. Daubrée, Compt. Rend. lxxxi., 1008–1010.

soluble gases, &c. In every way similar to this action is that by which the more insoluble silica is deposited in place of carbonate of lime in the formation of chert.

The views just stated are confirmed further by the fact, that in lists of pseudomorphs by displacement, the pseudomorphs are always the more insoluble bodies, silica (quartz, chalcedony and hornstone) especially, is never replaced by a mineral more soluble in water, but is frequently shown to replace calcite and the allied forms.*

Origin of the Nodular form of some Chert layers.—Although the cherty layers conform generally to the lines of bedding of the limestone, they usually occur in a more or less lenticular and nodular form. This may be explained on the supposition, that although the calcareous matter forming the bottom of the carboniferous sea would be in a somewhat generally pasty condition, some parts would be more soluble in sea water than others. A small patch might thus be easily altered and more or less replaced by silica, whilst surrounding portions would be nearly or quite unaffected. Molecular attraction might also in such cases determine the deposition of silica near the first particles deposited.

It would also depend much, both on the homogeneity of the limestone and the rate of its deposition, whether thick and regular beds or merely nodules and patches of chert were formed, but it appears clear that any given bed of chert must have been formed before the overlying bed of limestone was formed, for it always conforms to the bedding, and is never found in cracks or joints.

Source from whence the Silica was obtained.—Professor Hull has referred to the physical conditions of the period, and shown that the sea gradually became shallower, while the supply of silica as denoted by the predominance of chert in the upper beds must have increased. It may not be out of place here to point out that all the high ground surrounding the Irish carboniferous sea was composed of highly siliceous and felspathic rocks. On the west, the granitic and metamorphic rocks of Galway and Mayo; on the north, those of Donegal and Tyrone; and on the east, the Wicklow granites. The temperature of the time was high, and the atmosphere contained a much greater proportion of carbonic acid, than that of the present day. Under these circumstances the decomposition of such rocks would go on rapidly. The silicates would be quickly attacked by carbonic acid, the bases removed as soluble carbonates, while a quantity of silica (large compared to that which would be taken up at the present day) would be dissolved and carried down into the sea by river waters. As Dr. T. Sterry Hunt has shown, a very large amount of silica in solution is carried into the sea by rivers at the present time, and we are entitled to believe that a much greater amount was dissolved under the more favourable conditions existing during the carboniferous period, while with a sea gradually shallowing and consequently a more perceptible evaporation—the silica so brought down would be the more likely to substitute itself for the carbonate of lime.

* See Brooke and Miller's Ed. of Phillips' Mineralogy—List of Pseudomorphs, pp. 100–105.

TRANSACTIONS (NEW SERIES) VOLUME I.

(Already Published.)

[December, 1878.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (NEW SERIES).

VIII.—*On the Superficial Tension of Fluids and its Possible Relation to Muscular Contractions.* By G. F. Fitzgerald, m.a., f.t.c.d. [Read 17th June, 1878.]

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1878.

VIII.—ON THE SUPERFICIAL TENSION OF FLUIDS AND ITS POSSIBLE RELATION TO MUSCULAR CONTRACTIONS. By G. F. FITZGERALD, M.A., F.T.C.D.

[Read June 17, 1878.]

I.

Some of the latest contributions to the subject of the superficial tension of fluids are due to Mr. Lippmann's very remarkable researches into the connexion between surface tension and the difference of electrical potential at the contact of dissimilar fluids.* In connexion with these the lately published experiments of Messrs. Ayrton and Perry (see Proc. R. Soc., vol. xxvii., p. 196) are of great interest, and their conclusions are especially gratifying to me because some years ago, in the spring of 1875, I made some experiments, which seemed to me to show that much of the observed electromotive force of contact was accompanied by chemical action. I remark in a note I took on Friday, 19th March of that year, on some experiments made with varnished zinc and copper condensers ". . . . . . there always seemed an electromotive force in the air near the Zn . . . . . not like contact theory, for it resuscitated itself after bringing the poles to the same potential." Similarly Messrs. Ayrton and Perry consider that the electromotive force of contact of dissimilar substances is accompanied, in most cases, at least, by chemical action of some kind, although the amount is so small as to escape the ordinary means of analysis. Now, it seems to me that this sort of chemical attraction, which only culminates in chemical action in some cases, may be used to explain superficial tensions generally, and M. Lippmann's results. For instance, if we suppose the superficial tension to depend upon this chemical attraction, we can easily see how it is affected by the direction of the current passing from one surface to the other; for we know, by the phenomena of electrolysis, that the direction of the current alters, and even reverses, the character of this chemical attraction. Similarly Professor C. Maxwell mentions in his article on Capillarity, in the last edition of the Encyclopædia Britannica, that when a mercury surface is being extended there exists an accompanying electrical displacement. Sir W. Thomson, in his method of calculating the effective size of molecules by means of the observed difference of electrical potential on contact of zinc and copper, assumes that the actual chemical attractive forces are measurable by means of the attraction of the zinc and copper plates. From exactly similar premisses I propose calculating the superficial tension of a fluid. We require to know the electrical distribution corresponding to the contact of dissimilar substances, and I shall assume each molecule to be charged with that known quantity which passes when an electro-chemical equivalent is pro-

* Annales de Chimie et Physique, 5^{me} Serie, Vol. XII., p. 265.

duced. Any such assumption as that the electrical distribution would produce the observed electrical potential is evidently inadmissible, because then the effects would vary with the forms of the surfaces, which is not the case. Hence, if χ be the quantity of electricity employed in producing one electro-chemical equivalent, and if n be the number of such equivalents in presence of one another per unit of area of surface in contact, and if A be the area of contact, and ϵ the electromotive force of contact, and T the superficial tension per unit of length, we have the two equivalent expressions for the superficial energy,

$$\mathrm{T}.\mathrm{A} = n.\chi.\mathrm{A}\,\epsilon. \text{ or}$$
$$\mathrm{T} = n\chi\epsilon.$$

To approximate to a numerical calculation we must make some assumption. Thus, if we take the case of water, and assume N to be the total number of electrochemical equivalents in a gramme, and if we employ the C. G. S. system of units,

$$\mathrm{T} = 106.\frac{n}{\mathrm{N}}.\epsilon,$$

and if we assume T$=$·08 gr. per centimeter, or $=78·5$ dynes per centimeter, and $\epsilon = 10^7$ or the tenth of a volt, we have $\frac{\epsilon}{\mathrm{T}} = \frac{10^7}{78·5}$, and consequently

$$\frac{n}{\mathrm{N}} = \frac{78·5}{106}·10^{-7} = 7·3 \times 10^{-8},$$

so that if this were a surface of unit area, and thickness θ so small that all the particles are within reach of the surface, we should have $n = \mathrm{N}\theta$, and consequently

$$\theta = 7·3 \times 10^{-8}$$

which approximates towards the quantities obtained by other methods. The most doubtful assumption I have made is that the electromotive force of contact of air and water is a tenth of a volt, but this is not impossible.

I conclude, then, that superficial tension is solely due to this chemical attraction of dissimilar substances, as *some part of it, at least, must be due to this cause which produces a potential energy of the masses depending directly upon the area of the surfaces in contact.* I may mention that it seems to me likely that frictional electricity is due to a similar cause, and that it may be compared with Maxwell's experiment of the electrical current produced by altering the surface of mercury. In the same connexion compare Mr. Clark's experiments, as published in Wiedemann's Annalen der Physik und Chemie., Neue Folge, Band II., on the electrical potential of water driven through capillary tubes.

II.

I intend to devote this second part of my paper to developing the possible connexion between surface tension and muscular action.

It is known that muscles when they contract, alter little or not at all in bulk, and it seems, therefore, likely that the alteration in arrangement that they undergo is a change of superficial area of their component parts. Now, if we assume a muscle

to be composed of a number of circular fibres, each the $\frac{1}{200}$th of a centimeter in diameter, and each of these to consist of closely-packed fibrillæ, and to facilitate computation, if we assume each fibrilla to be of a triangular section, and the side of each triangle to be the $\frac{1}{8000}$th of a centimeter in length, these quantities being about the amounts observed in mammalian muscles, it is easy to calculate that there will be about 500 meters of circumference of fibrillæ per square centimeter of muscle which, with a superficial tension equal to that of water, gives a disposable force of four kilograms per square centimeter. The amount observed is about 7 kilograms per square centimeter,* and I think that what I have obtained comes sufficiently close to that observed for a more advantageous mode of distribution of the fibrillæ or a slight diminution of their size to account for the difference. Taking the thickness of the active superficial layer to be that obtained in the first part of this paper, the maximum force which could be obtained by making the structure as fine as possible, and the superficial tension that of water, would be nearly 1,000 kilograms per square centimeter, so that there is plenty of margin for compensating diminished superficial tensions by increased fineness of structure. It is remarkable in this connexion that in frogs, whose muscles are more coarsely made, the maximum contractile force falls very much below that of the mammalia. A system of elongated cylindrical fibrillæ would not be in stable equilibrium, but would break up into short lengths of less than three times their diameter, and this is just what is observed to be the case in all striated muscles. It has been questioned whether the fibrillar divisions and transverse striæ to be found in dead muscles, have an actual existence in life. Yet I think there can be little doubt but that some structural peculiarity in life corresponds to these sub-divisions, and any such would produce a superficies capable of developing superficial tension. It may seem improbable that as high a superficial tension as that of water can exist in this case, but the undoubted fact of considerable electrical disturbance accompanying muscular contraction taken in connexion with M. Lippmann's experiments proving the connexion between differences of electrical potential and superficial tensions, very much diminishes the force of this objection. If we suppose a structure to consist of a series of ellipsoids of revolution of ellipticity $=\sin\theta$ and if r be the radius of the sphere whose volume is equal to that of each cell, then the force each would exert in the direction of its axis for surface tension=T is given by the equation,

$$F=T\frac{\pi r\cos^{\frac{1}{3}}\theta}{2\sin^3\theta}\{\sin\theta\cos\theta(1+2\cos^2\theta)-\theta(4\cos^2\theta-1)\},$$

and it is easy to see that there is some given form of ellipsoid of revolution of given volume for which this force will be a maximum, as it vanishes in the two extreme cases of a sphere and an infinite cylinder. If we calculate the pressure in a cylinder of radius r, whose sides are formed of a series of rings like anchor rings, we find that the pressure is given by the equation,

$$P=\frac{\pi T}{2r}$$

and is independent of the section of each ring, so that by piling a great number of

* See Haughton's Animal Mechanics, pp. 63–71.

very thin rings upon one another, a very great pressure might be developed, though of course the outer ones would be less effective on account of the greater value of r. The case of the heart is somewhat similar to this.

A constant supply of fresh blood is necessary to keep up the irritability of a muscle, because after each contraction the surfaces at which the superficial tension has increased have been altered chemically, and it is necessary to remove this debris and renew the surface in order to let the muscle relax. We see thus how it happens that a contracted muscle requires a constant stimulus to keep it so, and why keeping it contracted tires the muscle, though no external work is performed. For, as there is, during life, a continual renewal of the surfaces of the fibrillæ, there is required a constant stimulus to keep them as continually changed into the altered state in which the superficial tension is increased, while after death *rigor mortis* sets in, because this altered state then becomes the permanent one.

A remarkable confirmation of my theory is that it completely explains the fact of a muscle's heating when it contracts. Whenever the area of any fluid surface is increased it cools, and when it is diminished it heats, and this is true of all fluids yet observed, for the superficial tension uniformly diminished when the temperature increases, and the law I have just mentioned is a direct consequence of this fact and of the laws of Thermodynamics.* Hence, when a muscle contracts, if this be accompanied by a diminution of superficial extension, we should expect it to heat, which is what actually takes place.

In the 58th number of the *Quarterly Journal of Science*, Dr. Stanley Jevons has published a most interesting paper upon what are known as the Brownian motions of small particles suspended in a fluid, and attributes them to a very slight chemical action producing electrical currents, but he does not explain how the currents produce motion. Now, although such a high authority as Faraday discarded surface tension as an explanation of these movements, nevertheless it has been reproposed by Tyndal as a possible explanation, and I think the motion of a drop of mercury in a horizontal glass tube when an electric current traverses some dilute acid surrounding the mercury is a very analogous phenomenon, only that the origin of the differences of electrical potential in the one case is external to the immersed substance, and in the other case, is probably, as Dr. Jevons supposes, due to a very slight chemical action of the suspending fluid on the particle. This explanation is rendered the more probable by Messrs. Ayrton and Perry's having shown in the Proceedings of the Royal Society (loc. cit.) that almost every case of contact of dissimilar substances is accompanied by some chemical action. It is of course possible that these very small particles may be carried about by the continually moving ultimate molecules of the fluid, which are proved to be in constant motion by the phenomena of diffusion, but it is very improbable that such is the fact, though in that case no energy need be expended in order to keep up the motion which might consequently go on for ever. Considering the very complex chemical constitution of organic substances, it is similarly possible that muscular contractions are due to some rearrangement of the ultimate molecules constituting the muscle, but in that case it seems improbable that the

(* See the Theory of Heat, by Professor J. C. Maxwell, in the Text Books of Science Series, p. 291.)

volume would remain unaltered, and besides, their very complicated structure would then seem unnecessary.

NOTE ADDED NOVEMBER 26, 1878.—It may seem doubtful whether my assumption, that an electromotive force of contact exists at the surface of separation of a liquid and a gas is justified, especially as Messrs. Ayrton and Perry seem to assert the contrary. Nevertheless in a paper published in the *Philosophical Magazine* for August, 1878, Mr. Brown details some experiments which prove conclusively that there exists an electromotive force of contact at the surface of separation of a metal and a gas, and probably the same is true of a liquid and a gas. In the case he mentions the direction of the electromotive force between copper and iron, was reversed by substituting sulphide of hydrogen for air, and this shows that these electromotive forces are at least comparable to those which have been hitherto assumed to be due to the contact of the metals with one another.

It seems probable that the cohesion of molecules in matter and of groups of atoms in binary compounds, are phenomena of the same kind.

Considering the enormous liquid surface produced in the form of spray by Armstrong's electrical machine, it seems reasonable to explain its efficiency by the electrical displacements accompanying the enlargement and diminution of liquid surfaces.

Addendum to Part V.

Note:—Since publishing this paper, Mr. Stoney has called my attention to a point in which I inconsiderately misunderstood his paper in my allusion to it, on the first paragraph of page 63. What he has shown in the paper referred to is not that the distribution of velocities represented by two streams of unpolarised gas is the ultimate state towards which the gas tends when the number of molecules is indefinitely diminished, but that as long as there are considerable numbers of molecules present the actual state of the gas lies between that represented by mutually non-interfering streams and an unpolarised state. As the number of molecules diminishes indefinitely the tendency is towards a state which might be represented by the radii drawn from a common centre to two hemispheres of unequal radius turned in opposite directions, the one of larger radius being turned from the heater. In this case it is easy to see that there would be no difference between the pressures in the direction of the transference of heat and in the perpendicular direction, and consequently no Crookes's force.

Corrigenda to Part V.

Page	57,	line	12	from	top,	for	presure	read pressure.
,,	61,	,,	6	,,	bottom,	,,	κ	,, K.
,,	62,	,,	7	,,	top,	,,	κ	,, ,,
,,	66,	,,	11	,,	bottom,	,,	κ	,, k.
,,	67,	,,	9	,,	top,	,,	κ	,, K.

TRANSACTIONS (NEW SERIES) VOLUME I.

(Already Published.)

[February, 1879.]

THE SCIENTIFIC TRANSACTIONS OF THE ROYAL DUBLIN SOCIETY.

VOLUME I. (NEW SERIES).

IX.—*Places of One Thousand Stars observed at the Armagh Observatory.* By Rev. Thomas Romney Robinson, D.D., LL.D., D.C.L., F.R.S., &c. [Read January 21st, 1878.]

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1879.

IX.—PLACES OF ONE THOUSAND STARS OBSERVED AT THE ARMAGH OBSERVATORY. By Rev. THOMAS ROMNEY ROBINSON, D.D. LL.D., D.C.L., F.R.S., &c.

[Read January 21st, 1878.]

The observations, on which the present catalogue is based, were made with the Armagh Mural Circle, described in the Transactions of the Astronomical Society, Vol. IX., and in the preface to the Armagh Star Places. It was constructed with a view to its possible employment as a transit instrument, having cylindric pivots turning in Ys of 60°. However, it was not so used till I formed the plan of re-observing those of the smaller stars of the *Histoire Céleste* which had not been recently determined. For this work the Armagh instruments were scarcely adequate from the small size of their object glasses (3·75 aperture), which in the atmosphere of this island has often too little light to show faint stars. It was impossible to fit a larger one to the transit instrument; but with the circle it was possible, and the liberal bounty of the late Primate, Lord John Beresford, enabled me to effect it. A new telescope was attached to the steel axis which carried the old one; it was eighty pounds heavier, but the effect of this was obviated by altering the counterpoise and adding another to the end of the axis, so as to keep the C. G. of the instrument still in the plane of its friction-wheels.

The arrangements of the room required that its focal length should be nearly the same as that of the old one; it is 68 inches, but its aperture is 7″ clear. It was made by Mr. Grubb, F.R.S.; and its object glass is peculiar. It consists of two achromatic lenses, each cemented, so that there are only four reflecting surfaces, as in ordinary objectives, and the glasses are of remarkable transparency. The definition and light are excellent. To its north and south two collimators are fixed on insulated pillars, which, when the telescope is vertical, see each other through apertures in it (ordinarily covered by pieces easily removed). The collimation is very permanent. The level is got by observing the reflection of the wires. If the direct and reflected images of the centre coincide, level is right; if they do not, the error is measured thus:—A draw-tube of the eye-piece contains a double-image prism, and carries a divided circle whose verniers read 90° when the wires appear single; then by turning the tube till the direct and reflected images coincide the level error is $\frac{1}{2} \times 16''. 94 \times \cos \theta$. Azimuth error can be similarly measured from the meridian mark.

There seems very little flexure in the telescope; fifteen of the angles between the collimators gave its horizontal value 0·11″; this is probably due to the shortness, and large diameter of the tube, and to its being clamped at each end to the circle, the framing of which is very strong. Another error gave us some trouble. In winter all was right, but as summer came on it was observed that if the object glass was lowered from the south to the Nadir, the index correction obtained was available through the entire southern semicircle, but if it was lowered from the north the correction was as much as 4″ less, but availed for the northern semicircle. The cause was obvious; in the cold weather the brass cells fitted the lenses tightly, but their expansion gave these play to shift by their own weight. Mr. Grubb remedied this by supporting the lenses on three equidistant bearings; two fixed at 60° east and west of the meridian; the third moveable, and pressed inwards by a spring, whose tension is a little more than the weight of the glass. And now the cell is of cast-iron, whose expansion is little more than half that of brass. These changes have proved so effectual that the difference of the index corrections is reduced to 0·07″.

Some precautions, which need not be described, were required to prevent the iron, which carried the Ys, from a slight rocking motion when the circle was turned, and the clamps from exerting any lateral force which might disturb the azimuth or level.

The mode of observing Polar distances is fully explained in the preface to the Armagh Star Places; so I will only describe that of Right Ascension. The telescope has a system of seven wires, designed for the usual mode of observing transits; but, as I proposed, to use a chronograph these would have occupied too much time, and, therefore, two supplemental wires were added on each side of the central one, the equatorial intervals of this system being about 3 seconds. The illumination of the field is made by a small inclined central mirror, 0·4″ in diameter, carried on a thin arm supported by the cover of one of the collimating apertures; and its intensity is controlled by a regulator containing three slips of orange glass, which can be combined by the observer.

The chronograph was made by Knoblech of Altona, and is similar to that described by Dr. Peters in the Astron. Nach, XLIX., 1, except that as I was dissatisfied with the action of the conical pendulum by which it was regulated, Mr. Howard Grubb substituted a governor such as he applies to the driving clocks of his equatorials. On its records $\frac{1}{8}$ of an inch represents a second of time. In this mode of observing the probable error of an equatorial star's transit is $\pm$ 0ˢ. 080, and of a single PD 0″. 816. For Zenith stars these are $\pm$ 0ˢ. 0995 and $\pm$ 0″. 723, each deduced from 100 observations.

On each night five standard stars were observed, both for clock correction and to check the Azimuth of the instrument.

Lalande's places were brought up to the time of observation by the precessions

given in Baily's Lalande; from these the star constants were computed by tables (almost identical with those recently published by Mr. Stone) which I constructed more than forty years ago.

The reduced observations were brought to 1870 by the precessions and secular variations of the British Association's catalogue.

The present catalogue gives the number of the star in the Lalande catalogue; its magnitude as given in that catalogue, except where it was manifestly erroneous; the number of observations; their mean epoch; the AR for 1870; the precession and secular variation for the same date; and in some cases the proper motion. Next, the same for Polar distance; and lastly, reference to other observers who have noticed the star. The observations and reductions were all made by my assistant, the Rev. Charles Faris.

No.	Star.	Mag.	AR for 1870.	Prec.	Sec. Var	Obs.	Mean Epoch	N.P.D. for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.
1	LL 2	7½	0 3 41·57	+3·104	+0·047	4	72·561	33 33 29·77	−20·050	+0·014	4	72·561
2	,, 10	7	0 3 49·51	3·085	0·021	4	70·874	57 35 33·77	20·050	0·014	4	70·874
3	,, 32	6½	0 4 30·31	3·069	−0·0003	4	73·576	94 2 41·01	20·049	0·015	5	73·624
4	,, 68	7½	0 5 27·33	3·097	+0·012	4	72·548	50 49 18·30	20·047	0·017	5	72·983
5	,, 220	7½	0 9 56·56	3·113	0·024	5	71·838	54 13 59·84	20·034	0·026	5	71·838
6	,, 230	7	0 10 4·31	3·081	0·007	5	75·335	80 28 41·65	20·034	0·025	4	75·415
7	,, 345	7½	0 13 29·30	3·107	0·017	4	71·848	66 3 22·06	20·018	0·032	5	72·242
8	,, 367	6	0 13 57·82	3·122	0·026	4	73·769	57 48 36·14	20·015	0·034	4	73·769
9	,, 373	7½	0 14 5·61	30.97	0·012	4	75·130	72 14 26·12	20·014	0·036	4	75·130
10	,, 441	7½	0 16 45·43	3·157	0·030	4	72·338	48 39 51·59	19·999	0·040	4	72·338
11	,, 484	7½	0 18 7·62	3·216	0·080	5	71·994	42 40 25·31	19·990	0·043	5	71·619
12	,, 504	7½	0 18 30·87	3·159	0·028	4	74·591	50 53 24·68	19·987	0·044	5	74·437
13	,, 558	7	0 20 11·67	3·208	0·039	5	71·065	40 44 3·42	19·975	0·047	5	71·065
14	,, 607	7½	0 21 30·39	3·205	0·038	4	71·795	42 59 36·05	19·964	0·050	4	71·795
15	,, 613	7	0 21 35·70	3·153	0·023	5	74·668	56 55 11·16	19·963	0·050	6	74·527
16	,, 761	6	0 25 43·72	3·147	0·018	5	71·450	63 8 13·65	19·927	0·057	5	71·450
17	,, 788	7½	0 26 31·56	3·198	0·030	4	74·638	50 36 43·71	19·919	0·058	4	74·638
18	,, 849	7	0 28 12·45	3·190	0·027	5	71·620	53 53 4·61	19·901	0·063	4	71·826
19	,, 892	7	0 29 10·80	3·107	0·008	4	74·668	77 30 13·64	19·889	0·056	4	74·668
20	,, 1100	7½	0 35 14·49	3·263	0·035	5	70·450	46 46 31·56	19·817	0·077	4	70·365
21	,, 1113	7½	0 35 33·98	3·176	0·020	4	72·586	63 4 14·12	19·812	0·077	4	72·586
22	,, 1202	7½	0 38 39·63	3·193	0·021	5	70·609	61 31 17·12	19·768	0·084	4	70·564
23	,, 1210	7½	0 39 8·91	3·447	0·063	4	73.124	31 8 12·08	19·761	0·090	4	73·124
24	,, 1236	7½	0 39 38·77	3·305	0·036	3	73·790	44 20 47·81	19·756	0·085	4	72·566
25	,, 1272	7	0 40 43·53	3·149	0·014	4	73·067	71 48 34·14	19·737	0·087	4	73·067
26	,, 1414	6	0 44 53·37	3·241	0·026	5	70·655	56 49 1·33	19·669	0·099	4	70·621
27	,, 1462	7½	0 46 22·59	3·319	0·036	4	70·659	47 20 19·82	19·644	0·103	4	70·659
28	,, 1539	7½	0 48 20·24	3·232	0·023	5	70·847	60 2 38·64	19·608	0·106	5	70·473
29	,, 1544	7	0 48 24·28	3·219	0·022	4	73·392	62 8 39·57	19·607	0·104	4	73·392
30	,, 1585	7½	0 49 39·57	3·225	0·023	5	73·481	61 54 22·18	19·583	0·107	5	73·481
31	,, 1625	7½	0 50 47·63	3·271	0·026	4	71·844	55 42 59·43	19·562	0·111	4	71·844
32	,, 1663	7	0 52 0·72	3·257	0·024	4	70·054	58 14 49·65	19·539	0·112	3	69·808
33	,, 1665	7	0 52 1·74	3·224	0·021	5	71·874	63 2 46·29	19·539	0·110	5	71·874
34	,, 1854	6	0 57 21·54	3·254	0·021	5	70·864	61 2 8·44	19·427	0·115	4	70·882
35	,, 1912	7½	0 59 35·26	3·307	0·028	4	71·797	55 33 3·12	19·382	0·126	4	71·797
36	,, 1943	7½	1 0 19·83	3·429	0·036	5	70·864	43 51 12·39	19·362	0·134	4	70·882
37	,, 2132	7	1 5 16·96	3·319	0·027	5	70·663	56 34 16·09	19·244	0·143	4	70·631
38	,, 2293	6½	1 10 11·39	3·314	0·025	3	70·554	58 56 31·62	19·120	0·150	5	71·095
39	,, 2403	6½	1 14 4·04	3·567	0·049	4	71·367	40 33 36·30	19·016	0·167	5	71·095
40	,, 2597	6½	1 19 32·95	3·300	0·022	5	74·324	63 25 42·53	18·857	0·169	5	74·324

No.	Star.	Mag.	AR for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.	N.P.D. for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.
41	LL 2814	7½	1 26 27·21	+3·415	+0·030	5	72·282	55 3 37·58	−18·646	+0·184	5	72·282
42	,, 2950	7½	1 30 15·49	3·300	0·012	4	72·109	65 29 20·87	18·518	0·190	4	72·109
43	,, 2996	7	1 32 17·64	3·199	0·017	4	71·898	76 22 32·24	18·484	0·184	5	72·131
44	,, 3267	7½	1 40 28·19	3·034	0·005	4	71·634	93 45 56·67	18·162	0·186	4	71·634
45	,, 3310	7	1 42 9·63	3·350	0·021	5	70·662	64 10 29·94	18·093	0·216	6	70·076
46	,, 3596	7	1 50 36·73	3·399	0·023	4	71·163	62 6 53·61	17·766	0·230	6	70·415
47	,, 3689	7½	1 53 27·78	3·183	0·013	5	73·102	80 0 6·17	17·646	0·223	5	73·102
48	,, 3682	7½	1 53 32·32	3·418	0·025	4	69·652	61 23 33·24	17·644	0·239	4	69·652
49	,, 4296	6½	2 12 28·56	3·486	0·025	4	71·504	60 24 38·12	16·794	0·283	5	71·504
50	,, 4377	7	2 15 39·14	3·590	0·030	5	70·991	55 9 8·09	16·642	0·296	5	70·991
51	,, 4415	7	2 17 6·15	3·482	0·025	5	71·929	61 20 49·15	16·571	0·289	6	71·427
52	,, 4493	7	2 19 29·60	3·435	0·037	5	70·385	64 32 41·04	16·452	0·290	6	69·465
53	,, 4601	7	2 23 24·32	3·881	0·044	4	74·849	43 59 31·49	16·255	0·331	4	74·849
54	,, 4627	7½	2 23 49·04	3·674	0·033	4	70·718	52 27 20·36	16·233	0·317	4	70·718
55	,, 4681	6	2 24 46·69	3·096	0·007	5	71·968	88 18 39·07	16·187	0·265	5	71·968
56	,, 4720	7½	2 26 24·62	3·593	0·029	4	73·159	56 46 50·72	16·098	0·316	5	72·311
57	,, 4752	6	2 27 38·49	3·670	0·032	4	70·515	53 15 29·90	16·035	0·323	4	70·515
58	,, 4765	7	2 28 19·30	3·792	0·039	5	70·726	48 10 6·75	15·998	0·336	5	70·726
59	,, 4799	7	2 29 11·87	3·732	0·031	5	71·969	50 40 17·56	15·951	0·334	5	71·969
60	,, 4867	7	2 32 17·61	4·608	0·095	4	71·225	28 12 7·00	15·787	0·411	4	70·727
61	,, 5114	7½	2 39 15·28	3·582	0·026	5	72·793	59 9 7·67	15·404	0·337	5	72·793
62	,, 5134	7½	2 39 48·65	3·425	0·020	6	70·803	67 35 10·66	15·372	0·324	6	70·803
63	,, 5176	7½	2 41 20·86	3·718	0·031	5	70·118	53 13 1·79	15·285	0·353	6	68·443
64	,, 5205	7½	2 42 13·07	3·572	0·025	4	72·466	60 0 51·01	15·239	0·337	4	72·466
65	,, 5257	7½	2 44 4·49	3·722	0·032	5	71·182	53 26 35·62	15·130	0·359	5	71·182
66	,, 5365	7	2 47 51·08	3·598	0·026	4	71·214	59 29 10·89	14·912	0·351	5	70·966
67	,, 5435	7½	2 50 9·24	3·614	0·026	4	72·715	59 0 28·93	14·775	0·360	5	71·956
68	,, 5440	7½	2 50 23·46	3·635	0·027	5	73·206	58 3 56·93	14·762	0·362	5	73·206
69	,, 5481	6	2 51 58·16	3·773	0·032	5	70·154	52 23 17·29	14·668	0·377	4	70·435
70	,, 5540	7	2 53 32·84	3·639	0·025	4	72·758	58 6 15·97	14·565	0·425	4	72·758
71	,, 5636	7½	2 57 9·73	3·947	0·039	5	70·116	46 48 23·46	14·354	0·404	5	70·116
72	,, 5690	7	2 58 53·79	4·072	0·044	5	72·207	43 11 45·11	14·246	0·421	5	72·207
73	,, 5769	7½	3 1 32·00	4·037	0·043	5	71·185	44 33 29·16	14·085	0·419	4	71·723
74	,, 5830	7	3 2 37·14	3·443	0·018	5	73·195	68 45 1·69	14·017	0·363	5	73·195
75	,, 5953	7	3 6 31·79	3·396	0·017	5	72·205	71 30 56·88	13·771	0·363	5	72·205
76	,, 6079	7½	3 10 14·03	3·180	0·010	5	71·955	83 40 48·42	13·543	0·332	5	71·955
77	,, 6142	7½	3 12 56·93	3·422	0·017	4	69·987	70 36 3·08	13·356	0·376	4	69·987
78	,, 6166	7	3 13 19·63	3·089	0·009	4	73·236	88 59 24·16	13·331	0·340	4	73·236
79	,, 6275	6½	3 16 56·90	2·924	0·006	5	71·559	98 15 6·78	13·093	0·327	5	71·559
80	,, 6302	7	3 18 42·45	3·619	0·023	5	70·557	61 44 23·52	12·977	0·404	5	70·557

No.	Star.	Mag.	AR for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.	N.P.D. for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.
81	LL 6392	7	3 22 2·02	+3·992	+0·036	5	70·163	48 14 47·61	−12·754	+0·450	5	70·163
82	„ 6475	6	3 23 51·27	3·176	0·011	4	73·463	84 15 30·31	12·631	0·363	4	73·463
83	„ 6494	7½	3 25 12·82	3·874	0·029	4	70·425	52 25 41·96	12·543	0·434	4	70·425
84	„ 6634	6	3 28 22·41	2·879	0·006	4	73·442	100 18 20·64	12·320	0·334	4	73·442
85	„ 6668	7½	3 31 36·29	4·160	0·039	4	72·036	44 24 7·00	12·096	0·484	4	72·036
86	„ 6764	7½	3 34 38·06	4·067	0·036	4	71·739	47 14 58·27	11·871	0·496	4	71·739
87	„ 6820	6	3 36 6·85	3·858	0·028	5	71·328	53 57 10·09	11·780	0·457	5	71·328
88	„ 6991	5½	3 40 39·27	3·537	0·017	4	71·520	66 58 50·61	11·455	0·426	4	71·520
89	„ 7003	7	3 41 31·11	3·914	0·028	5	70·573	52 31 29·09	11·394	0·470	4	70·958
90	„ 7106	7	3 44 27·76	3·765	0·023	5	71·811	57 59 0·95	11·179	0·459	5	71·811
91	„ 7185	7	3 47 15·65	3·726	0·009	5	71·014	59 20 22·57	10·976	0·457	5	71·014
92	„ 7236	7½	3 49 6·05	3·892	0·025	4	71·484	53 53 7·43	10·842	0·479	4	71·484
93	„ 7266	6	3 49 34·75	3·502	0·016	5	71·988	69 3 23·16	10·807	0·431	5	71·988
94	„ 7294	7	3 50 35·45	3·567	0·017	4	72·014	66 17 40·57	10·731	0·441	4	72·014
95	„ 7422	6	3 53 24·37	2·809	0·005	5	70·969	102 56 41·73	10·522	0·353	5	70·969
96	„ 7383	7½	3 54 23·43	4·683	0·053	5	72·377	35 17 44·11	10·447	0·583	5	72·377
97	„ 7419	7½	3 54 36·93	3·924	0·025	5	71·635	53 14 40·74	10·430	0·491	5	71·635
98	„ 7514	7	3 57 21·88	3·766	0·021	5	72·201	58 51 37·58	10·224	0·474	5	72·201
99	„ 7561	7½	3 58 36·69	3·823	0·022	5	70·568	56 54 28·32	10·128	0·484	5	70·568
100	„ 7661	7½	4 1 4·86	3·576	0·016	5	72·391	66 28 36·38	9·945	0·454	5	72·391
101	„ 7683	7	4 2 17·55	4·098	0·028	5	71·765	48 35 36·84	9·854	0·519	5	71·765
102	„ 7899	7½	4 7 41·00	3·790	0·020	5	72·008	58 38 4·78	9·438	0·490	5	72·008
103	„ 7936	7½	4 8 18·89	3·131	0·007	4	74·009	87 4 58·54	9·390	0·406	4	74·009
104	„ 7982	6½	4 9 6·37	2·720	0·005	4	72·000	106 30 30·48	9·330	0·351	4	72·000
105	„ 8020	7½	4 10 31·64	3·117	0·008	4	73·748	87 47 36·08	9·219	0·404	4	73·748
106	„ 7975	7	4 11 17·75	4·847	0·051	5	70·975	33 48 35·21	9·160	0·626	5	70·975
107	„ 7983	7	4 11 52·32	5·077	0·060	4	72·013	30 41 44·33	9·116	0·654	4	72·013
108	„ 8040	6½	4 11 53·61	3·805	0·019	4	74·009	58 21 49·02	9·113	0·496	4	74·009
109	„ 8103	6	4 14 33·12	4·153	0·027	4	71·784	47 52 46·26	8·949	0·543	4	71·784
110	„ 8171	7½	4 15 49·70	3·910	0·021	5	71·177	55 3 58·69	8·804	0·513	5	71·177
111	„ 8198	7½	4 15 58·50	3·572	0·012	4	73·504	67 20 28·61	8·869	0·358	4	73·504
112	„ 8139	7½	4 16 13·91	4·943	0·052	5	72·023	32 42 55·39	8·772	0·649	5	72·023
113	„ 8248	7½	4 17 56·05	4·346	0·032	4	71·784	43 26 3·58	8·639	0·570	4	71·784
114	„ 8342	7	4 19 10·06	3·157	0·007	5	72·624	85 55 29·43	8·525	0·443	5	72·624
115	„ 8344	7½	4 19 33·64	3·462	0·012	4	70·441	72 5 18·92	8·511	0·457	4	70·441
116	„ 8458	7	4 22 11·48	2·734	0·006	5	72·599	105 28 23·59	8·301	0·366	5	72·599
117	„ 8468	7	4 23 25·09	3·590	0·013	5	73·015	66 56 15·61	8·203	0·480	5	73·015
118	„ 8455	6½	4 23 37·16	3·983	0·021	5	70·763	53 14 23·28	8·186	0·533	5	70·763
119	„ 8558	6	4 25 13·73	3·063	0·005	4	73·729	90 19 31·35	8·060	0·396	4	73·729
120	„ 8589	5	4 26 7·38	2·996	0·006	4	72·555	93 29 17·87	7·987	0·403	4	72·555

No.	Star.	Mag.	AR for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.	N.P.D. for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.
121	LL 8705	5½	4 30 35·74	+3·531	+0·012	4	69·985	69 34 44·80	−7·627	+0·476	5	69·963
122	„ 8726	6½	4 31 27·55	3·647	0·013	5	71·055	65 2 32·51	7·556	0·494	5	71·055
123	„ 8789	7½	4 33 59·93	4·049	0·020	5	69·963	51 49 31·69	7·349	0·550	5	69·963
124	„ 8804	7½	4 34 12·76	3·619	0·012	5	72·424	66 14 32·63	7·333	0·493	5	72·424
125	„ 8806	7½	4 34 54·94	4·198	0·021	5	72·238	47 49 48·70	7·262	0·589	5	72·238
126	„ 8825	7½	4 35 50·49	4·421	0·030	4	72·992	42 46 9·98	7·198	0·601	4	72·992
127	„ 8892	6½	4 37 46·35	4·124	0·022	5	69·963	49 55 36·76	7·041	0·563	5	69·963
128	„ 8943	6	4 38 47·98	3·325	0·009	4	71·039	78 32 5·33	6·958	0·457	4	71·039
129	„ 8969	7½	4 39 27·59	3·137	0·006	4	72·018	86 58 18·14	6·904	0·431	4	72·018
130	„ 9037	6½	4 41 55·20	3·145	0·007	4	73·518	86 38 35·36	6·701	0·433	4	73·518
131	„ 9019	7½	4 42 5·87	4·039	0·019	5	70·177	52 28 8·20	6·686	0·554	5	70·177
132	„ 9018	7	4 42 53·29	4·722	0·033	4	72·521	37 22 55·94	6·620	0·651	5	72·521
133	„ 9072	7	4 43 52·35	3·829	0·014	5	71·060	59 3 20·17	6·539	0·530	5	71·063
134	„ 9195	6	4 47 19·89	3·515	0·010	4	70·045	70 43 39·04	6·255	0·486	4	70·045
135	„ 9260	7½	4 50 34·51	4·207	0·020	5	69·853	48 19 44·27	5·983	0·586	5	69·853
136	„ 9316	6½	4 50 41·50	3·048	0·014	4	73·313	91 16 19·46	5·971	0·426	4	73·313
137	„ 9332	7	4 51 48·16	3·726	0·011	5	72·423	62 52 25·48	5·880	0·520	5	72·423
138	„ 9409	7½	4 54 2·04	3·554	0·010	5	69·835	69 21 37·96	5·694	0·494	5	69·835
139	„ 9489	7½	4 55 55·22	3·144	0·006	5	72·040	86 43 55·19	5·535	0·440	5	72·040
140	„ 9504	6	4 57 19·99	3·998	0·014	4	71·247	54 14 43·70	5·415	0·563	5	71·617
141	„ 9594	7½	4 59 14·83	3·152	0·006	5	73·034	86 23 27·18	5·254	0·447	5	73·034
142	„ 9653	7	5 1 35·42	3·755	0·011	4	71·312	62 8 14·05	5·057	0·530	4	71·312
143	„ 9700	6	5 2 7·52	3·140	0·006	5	74·231	86 57 4·56	5·011	0·444	5	74·231
144	„ 9697	7½	5 3 13·26	4·156	0·016	5	71·224	50 3 43·59	4·917	0·587	5	71·224
145	„ 9769	7½	5 5 55·65	3·829	0·011	4	71·804	59 45 23·27	4·688	0·541	4	71·804
146	„ 9827	7½	5 9 2·34	3·787	0·009	4	72·071	61 14 30·40	4·423	0·539	4	72·071
147	„ 9831	7½	5 9 35·35	4·036	0·013	4	71·321	53 30 44·02	4·371	0·580	5	71·676
148	„ 9890	7½	5 11 25·10	4·039	0·012	4	70·491	53 27 50·06	4·218	0·574	4	70·491
149	„ 9955	7½	5 13 27·66	4·025	0·011	5	71·856	53 55 56·28	4·045	0·573	5	71·856
150	„ 10011	6½	5 15 5·82	4·033	0·012	5	71·010	53 43 42·64	3·904	0·577	5	71·010
151	„ 10041	6	5 16 0·16	4·027	0·011	4	70·549	53 55 27·07	3·827	0·576	4	70·549
152	„ 10168	7	5 19 48·08	3·979	0·009	4	71·309	55 24 54·59	3·500	0·570	4	71·309
153	„ 10209	6½	5 21 1·33	4·003	0·010	5	69·669	54 44 1·24	3·395	0·574	5	69·669
154	„ 10324	7	5 24 7·14	4·038	0·009	5	71·662	53 46 39·48	3·127	0·581	5	71·662
155	„ 10400	7	5 25 14·17	2·994	0·004	4	71·591	93 18 56·03	3·031	0·433	4	71·591
156	„ 10492	7½	5 28 2·72	3·369	0·009	5	70·688	79 50 55·88	2·788	0·479	5	70·688
157	„ 10489	7½	5 28 26·91	3·713	0·007	4	71·223	64 8 52·87	2·752	0·537	4	71·223
158	„ 10505	7½	5 29 29·45	4·253	0·009	4	70·820	48 14 28·30	2·663	0·613	4	70·820
159	„ 10607	7	5 31 38·63	3·599	0·005	5	71·268	68 18 47·30	2·476	0·520	5	71·268
160	„ 10630	7½	5 32 39·36	3·961	0·007	4	69·727	56 9 12·35	2·388	0·573	3	69·951

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161	LL 10843	6½	5 37 42·58	+3·374	+0·004	5	71·085	77 10 11·90	— 1·947	+0·491	5	71·085
162	,, 10871	6½	5 39 14·74	4·007	0·006	5	70·838	54 53 32·84	1·813	0·583	5	70·838
163	,, 10968	5	5 41 2·36	3·679	0·003	5	70·867	65 28 43·69	1·653	0·534	5	70·867
164	,, 11066	6½	5 44 37·18	4·087	0·006	5	70·017	52 41 54·13	1·344	0·594	4	70·019
165	,, 11253	7½	5 50 49·89	3·716	0·004	6	69·716	64 14 17·80	0·802	0·541	6	69·716
166	,, 11367	7½	5 54 6·60	3·925	0·003	5	69·652	57 24 50·21	0·533	0·547	5	69·652
167	,, 11458	7	5 56 58·88	3·959	0·003	5	71·872	56 23 48·69	0·262	0·581	5	71·872
168	,, 11493	7½	5 58 30·64	4·304	0·002	5	69·625	47 19 27·11	0·130	0·627	5	69·625
169	,, 11688	7½	6 2 10·89	3·130	0·001	4	71·616	87 28 54·93	0·191	0·456	4	71·616
170	,, 11694	7½	6 2 46·37	3·453	0·002	5	69·809	74 4 17·98	0·242	0·503	5	69·809
171	,, 11710	6	6 3 48·92	3·930	0·001	4	70·363	57 16 50·72	0·334	0·573	4	70·363
172	,, 11864	6½	6 7 17·61	3·420	0·001	5	69·908	75 22 39·96	0·639	0·499	5	69·908
173	,, 11989	6½	6 10 41·64	3·415	0·001	5	70·289	75 34 17·07	0·934	0·496	5	70·289
174	,, 12007	7	6 11 28·41	3·489	0·001	4	69·345	72 37 33·65	1·003	0·507	4	69·345
175	,, 12038	7½	6 12 10·95	3·455	0·001	5	70·686	73 56 10·10	1·065	0·503	5	70·686
176	,, 12070	7½	6 13 44·27	3·842	—0·001	4	70·869	59 58 44·40	1·201	0·559	4	70·869
177	,, 12134	7½	6 15 37·53	4·090	0·001	5	69·885	52 37 11·00	1·365	0·594	5	69·885
178	,, 12182	7	6 16 43·73	3·915	0·001	5	70·106	57 39 43·39	1·463	0·570	5	70·106
179	,, 12217	7	6 17 23·15	3·658	0·001	5	70·689	66 13 20·35	1·518	0·530	4	70·330
180	,, 12296	7	6 20 1·60	4·059	0·003	5	69·885	53 26 4·77	1·752	0·589	5	69·885
181	,, 12323	6½	6 20 12·64	3·571	0·000	5	69·877	69 25 42·37	1·768	0·519	4	69·829
182	,, 12325	7	6 20 22·98	3·588	0·009	4	72·367	68 45 57·53	1·781	0·521	4	72·367
183	,, 12387	7½	6 22 40·89	4·083	0·003	4	70·354	52 44 10·39	1·980	0·591	4	70·354
184	,, 12444	6	6 23 58·29	4·015	0·002	5	71·118	54 36 59·24	2·093	0·581	5	71·118
185	,, 12587	6	6 27 1·98	3·045	0·000	6	71·754	91 7 27·03	2·360	0·441	6	71·754
186	,, 12590	7½	6 27 30·77	3·437	0·001	5	70·506	74 34 15·55	2·401	0·497	4	70·879
187	,, 12716	6	6 31 33·16	3·680	0·003	4	72·573	65 17 29·55	2·752	0·531	4	72·573
188	,, 12751	6½	6 32 53·66	4·034	−0·006	4	70·649	53 56 59·95	2·869	0·583	4	70·649
189	,, 12825	5	6 33 20·46	2·740	+0·001	4	72·609	104 1 54·43	2·907	0·396	4	73·336
190	,, 12813	7	6 33 51·97	3·463	—0·001	5	69·489	73 29 1·01	2·952	0·500	5	69·489
191	,, 13048	6	6 41 12·87	3·917	0·006	5	70·323	57 14 54·01	3·587	0·561	5	70·323
192	,, 13055	6½	6 41 33·22	3·999	0·007	4	73·601	54 47 11·44	3·615	0·571	4	73·601
193	,, 13171	6	6 44 6·41	3·648	0·006	4	70·831	66 14 51·13	3·835	0·523	4	70·831
194	,, 13198	6	6 44 11·69	3·062	0·001	4	71·393	90 23 7·15	3·842	0·436	4	71·393
195	,, 13193	7½	6 45 41·02	4·427	0·012	4	70·606	44 0 44·97	3·971	0·633	5	71·108
196	,, 13339	6	6 47 48·22	3·049	0·000	3	70·170	90 57 59·04	4·152	0·433	3	70·170
197	,, 13321	7	6 48 29·17	4·076	0·008	5	71·102	52 26 21·58	4·210	0·580	5	71·102
198	,, 13496	7	6 52 18·91	3·242	0·002	5	70·535	82 30 28·42	4·537	0·459	5	70·535
199	,, 13485	7½	6 52 50·12	3·903	0·007	5	69·485	57 24 24·04	4·584	0·554	5	69·485
200	,, 13558	7½	6 55 23·92	4·511	−0·016	5	72·136	42 2 11·65	4·801	0·639	5	72·136

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201	LL 13648	6	6 56 25·94	+3·326	−0·005	5	70·494	78 51 37·73	+ 4·884	+0·471	5	70·494
202	,, 13810	7½	7 0 33·20	2·792	0·000	5	70·918	102 11 44·53	5·236	0·390	5	70·918
203	,, 13836	7½	7 1 44·92	3·169	0·002	4	72·120	85 37 12·16	5·337	0·443	4	72·120
204	,, 13849	7	7 2 23·82	3·581	0·002	5	69·918	68 31 45·04	5·394	0·503	5	69·918
205	,, 13915	7½	7 4 40·81	3·879	0·010	4	71·106	57 49 11·29	5·585	0·543	4	71·106
206	,, 13988	6½	7 6 3·58	3·390	0·004	5	70·737	76 1 10·23	5·700	0·470	5	70·737
207	,, 14035	7½	7 7 10·33	3·179	0·002	4	71·355	85 12 9·12	5·793	0·441	4	71·355
208	,, 14028	5	7 8 38·72	4·576	0·022	5	70·703	40 18 25·35	5·916	0·639	5	70·703
209	,, 14062	5½	7 8 59·43	4·185	0·017	5	70·704	48 53 19·62	5·947	0·585	5	70·704
210	,, 14282	7½	7 15 29·74	4·340	0·019	4	72·385	44 53 56·11	6·487	0·600	4	72·385
211	,, 14299	7½	7 15 36·70	4·009	0·013	5	70·739	53 26 25·23	6·497	0·554	5	70·739
212	,, 14435	6	7 19 17·88	3·312	0·005	5	70·541	79 8 8·49	6·800	0·453	5	70·541
213	,, 14406	6½	7 19 23·08	4·400	0·022	5	71·519	43 25 23·58	6·808	0·603	5	71·519
214	,, 14525	7	7 21 53·07	3·524	0·007	4	73·116	70 6 8·43	7·014	0·481	4	73·116
215	,, 14550	7½	7 22 33·65	3·552	0·008	5	70·753	68 56 57·68	7·069	0·483	5	70·753
216	,, 14575	7½	7 23 7·05	3·386	0·006	4	72·888	75 52 2·12	7·114	0·460	4	72·888
217	,, 14562	7	7 23 25·40	3·974	0·015	5	70·140	54 7 35·78	7·139	0·543	3	70·818
218	,, 14766	7½	7 29 11·99	4·215	0·021	5	72·737	47 14 46·47	7·609	0·569	5	72·737
219	,, 14759	7	7 29 28·87	4·588	0·030	5	70·742	39 10 46·28	7·633	0·620	3	71·822
220	,, 14921	7	7 33 11·45	3·601	0·008	5	69·493	66 40 59·48	7·851	0·366	5	69·493
221	,, 14928	7	7 33 28·66	3·379	0·006	5	73·110	75 55 52·06	7·954	0·451	5	73·110
222	,, 14934	6	7 34 17·72	3·907	0·016	5	72·933	55 41 52·90	8·020	0·523	5	72·933
223	,, 14974	6	7 34 26·45	2·743	0·002	5	71·110	104 57 52·89	8·033	0·367	4	71·590
224	,, 14966	7½	7 36 19·18	4·597	0·033	4	71·352	38 39 53·49	8·183	0·614	4	71·352
225	,, 15046	5½	7 37 58·30	4·016	0·019	4	70·104	52 10 12·80	8·296	0·507	5	69·909
226	,, 15092	7	7 39 20·54	3·611	0·010	6	70·782	66 1 12·39	8·422	0·476	5	71·101
227	,, 15136	5½	7 39 40·69	2·934	0·002	4	73·620	96 27 19·80	8·448	0·384	4	73·620
228	,, 15204	6½	7 42 44·62	3·822	0·016	5	72·926	58 3 35·42	8·692	0·502	5	72·926
229	,, 15230	6½	7 43 35·08	3·961	0·019	4	71·378	53 30 4·56	8·759	0·520	4	71·378
230	,, 15342	7	7 45 37·19	3·014	0·000	4	73·355	92 43 25·52	8·918	0·391	4	73·355
231	,, 15349	7½	7 45 53·25	3·149	0·005	6	70·271	86 16 58·32	8·939	0·410	6	70·271
232	,, 15335	7½	7 46 23·20	3·907	0·017	5	72·107	55 2 17·95	8·979	0·510	4	72·880
233	,, 15384	7½	7 47 36·97	3·897	0·017	4	72·876	55 17 26·01	9·073	0·504	5	72·114
234	,, 15459	7½	7 49 27·35	3·534	0·011	5	71·343	68 41 22·91	9·218	0·457	5	71·343
235	,, 15435	7½	7 49 29·50	4·211	0·026	5	73·502	46 9 2·02	9·221	0·546	5	73·502
236	,, 15501	7½	7 50 59·47	3·900	0·018	5	71·474	54 58 14·69	9·336	0·503	5	71·474
237	,, 15585	7	7 53 0·89	3·481	0·010	5	72·748	70 48 12·36	9·492	0·446	5	72·748
238	,, 15595	7	7 53 13·41	3·504	0·010	5	70·530	69 49 47·43	9·496	0·450	5	70·530
239	,, 15746	7	7 57 38·65	3·688	0·016	4	70·152	62 6 12·06	9·854	0·470	3	70·474
240	,, 15783	7½	7 58 48·58	3·819	0·019	4	72·904	57 12 54·34	9·937	0·484	4	72·904

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241	LL 15811	7½	7 59 58·30	+3·865	−0·019	5	70·528	55 35 34·33	+ 10·000	+ 0·489	4	70·643
242	„ 15961	6	8 2 46·81	2·848	0·001	5	73·137	100 57 43·24	10·236	0·353	5	73·137
243	„ 15943	7½	8 4 2·45	4·374	0·036	4	69·918	41 19 57·80	10·331	0·547	5	70·160
244	„ 16053	7	8 5 59·26	3·567	0·013	5	71·368	66 28 23·73	10·477	0·441	5	71·368
245	„ 16146	7	8 9 25·99	3·895	0·023	4	69·877	53 52 23·05	10·732	0·477	5	69·725
246	„ 16269	7½	8 12 24·43	3·890	0·008	5	70·608	53 48 50·47	10·950	0·471	5	70·608
247	„ 16350	7½	8 14 31·64	3·484	0·012	4	71·818	69 37 42·18	11·105	0·420	4	71·846
248	„ 16378	7½	8 15 41·80	3·790	0·010	4	70·684	57 17 30·56	11·191	0·456	4	70·684
249	„ 16489	7	8 17 57·62	3·262	0·007	4	69·856	80 9 17·02	11·356	0·390	4	69·856
250	„ 16486	7½	8 18 31·59	3·834	0·022	4	72·613	55 14 24·03	11·396	0·459	4	72·613
251	„ 16522	7½	8 19 29·32	3·884	0·024	4	71·419	53 26 59·30	11·466	0·464	4	71·419
252	„ 16631	7½	8 21 56·91	3·573	0·015	4	69·856	65 13 26·52	11·639	0·421	4	69·856
253	„ 16616	7½	8 22 25·58	4·416	0·045	5	70·736	38 56 13·62	11·676	0·524	3	70·426
254	„ 16663	7	8 22 35·84	3·240	0·007	4	73·891	81 9 7·41	11·687	0·381	4	73·891
255	„ 16814	6	8 26 52·08	3·168	0·006	4	73·403	84 48 5·02	11·989	0·367	4	73·403
256	„ 16823	6	8 27 12·88	3·239	0·008	5	71·168	81 6 16·05	12·013	0·376	5	71·168
257	„ 16869	7½	8 28 4·29	3·028	0·003	5	72·581	92 18 37·44	12·073	0·349	5	72·581
258	„ 16933	7½	8 30 23·08	3·599	0·017	4	70·428	63 29 34·60	12·235	0·414	4	70·428
259	„ 16987	6½	8 30 59·06	2·988	0·003	4	72·917	94 28 59·69	12·277	0·344	4	72·917
260	„ 17007	7½	8 31 39·10	3·092	0·004	5	72·373	88 51 22·10	12·322	0·353	5	72·373
261	„ 17049	7	8 33 56·78	4·207	0·041	6	69·591	42 38 5·55	12·480	0·480	6	69·618
262	„ 17081	7	8 34 19·06	3·797	0·019	4	71·951	55 20 26·89	12·504	0·430	4	71·951
263	„ 17111	7½	8 35 14·13	3·861	0·028	5	70·968	52 49 13·71	12·568	0·437	5	70·968
264	„ 17207	7½	8 37 56·17	3·768	0·024	5	70·735	55 56 30·69	12·751	0·423	6	71·303
265	„ 17327	7½	8 41 44·93	3·762	0·024	5	70·387	55 48 0·94	13·007	0·416	5	70·387
266	„ 17368	7½	8 42 49·60	3·788	0·026	5	70·372	54 41 37·20	13·079	0·420	4	70·667
267	„ 17512	7½	8 46 36·23	3·589	0·013	5	70·386	62 35 6·61	13·327	0·389	5	70·386
268	„ 17528	7½	8 46 47·47	3·489	0·015	5	73·174	67 17 28·88	13·340	0·377	5	73·174
269	„ 17584	7	8 48 34·63	3·532	0·017	5	69·950	65 3 18·57	13·455	0·379	4	70·169
270	„ 17750	7½	8 53 34·23	3·786	0·027	5	69·324	53 37 56·30	13·777	0·399	6	69·292
271	„ 17802	6	8 54 39·32	3·175	0·007	5	70·785	83 51 4·44	13·845	0·331	5	70·785
272	„ 17873	7½	8 57 24·74	3·783	0·028	5	69·554	53 18 13·87	14·020	0·394	4	69·645
273	„ 17899	7½	8 58 32·20	3·836	0·030	4	70·439	51 12 11·58	14·087	0·396	6	70·839
274	„ 17946	6½	8 59 44·19	3·656	0·023	5	71·182	58 16 41·85	14·164	0·374	5	71·182
275	„ 18016	7½	9 2 3·34	3·750	0·027	5	70·421	54 3 41·61	14·305	0·379	4	70·735
276	„ 18044	5½	9 2 46·94	3·643	0·023	3	71·560	58 30 32·87	14·351	0·369	5	72·607
277	„ 18079	7	9 3 49·85	3·748	0·026	5	68·573	53 59 15·59	14·418	0·380	7	68·714
278	„ 18120	6½	9 4 28·15	3·226	0·008	5	71·025	80 29 37·27	14·453	0·321	5	71·025
279	„ 18159	7½	9 5 30·55	3·006	0·002	4	71·472	94 1 27·46	14·518	0·300	4	71·472
280	„ 18216	7½	9 7 37·15	3·266	0·010	6	70·388	77 58 0·93	14·643	0·321	5	70·404

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281	LL 18251	6	9 8 42·19	+3·324	−0·012	5	70·384	74 27 7·07	+14·708	+0·327	5	70·384
282	„ 18289	5½	9 10 24·40	3·724	0·028	5	71·225	54 5 30·94	14·810	0·364	5	71·225
283	„ 18362	6½	9 12 50·02	3·784	0·033	5	72·199	51 15 47·04	14·946	0·357	5	72·199
284	„ 18394	6	9 13 48·07	3·643	0·025	5	70·822	57 11 4·44	15·008	0·350	5	70·822
285	„ 18422	7½	9 14 29·41	3·380	0·014	5	70·596	70 41 54·91	15·058	0·337	5	70·596
286	„ 18452	6½	9 15 52·49	3·688	0·027	4	70·988	54 53 43·17	15·126	0·350	4	70·988
287	„ 18488	7½	9 16 20·55	3·002	0·002	5	71·200	94 29 9·08	15·154	0·281	5	71·200
288	„ 18510	8	9 17 38·99	3·694	0·028	5	72·192	54 17 25·87	15·239	0·364	5	72·192
289	„ 18760	7½	9 26 20·97	3·661	0·027	6	71·231	54 36 48·45	15·713	0·330	6	71·231
290	„ 18775	7	9 26 33·60	3·441	0·017	5	70·837	65 58 5·42	15·724	0·309	5	70·837
291	„ 18810	7	9 27 51·78	3·655	0·028	5	72·424	54 38 25·29	15·795	0·326	5	72·424
292	„ 18867	7	9 29 44·29	3·571	0·024	4	70·243	58 27 39·54	15·892	0·310	5	70·243
293	„ 18921	7	9 31 12·89	3·262	0·011	5	71·421	76 40 50·70	15·973	0·283	5	71·421
294	„ 18966	7½	9 33 18·65	3·731	0·034	4	69·931	50 27 24·47	16·083	0·323	5	69·764
295	„ 18987	6½	9 33 53·16	3·569	0·024	5	70·443	58 7 58·43	16·085	0·308	5	70·443
296	„ 19084	7½	9 36 36·34	3·225	0·010	5	70·240	78 53 0·63	16·253	0·270	5	70·240
297	„ 19104	7½	9 38 2·85	3·732	0·019	4	72·738	49 33 58·95	16·329	0·316	4	72·738
298	„ 19173	6½	9 39 59·56	3·416	0·018	5	70·240	65 45 9·01	16·427	0·283	5	70·240
299	„ 19231	7½	9 41 54·44	3·327	0·014	4	72·731	71 20 21·39	16·522	0·271	4	72·731
300	„ 19244	6½	9 42 32·16	3·629	0·029	4	71·728	53 31 16·42	16·554	0·297	4	71·728
301	„ 19333	6½	9 45 51·35	3·599	0·030	5	70·554	54 24 21·05	16·719	0·293	3	71·253
302	„ 19371	7½	9 46 43·79	3·272	0·013	4	70·743	74 39 6·34	16·765	0·270	4	70·743
303	„ 19479	7	9 50 27·16	3·291	0·013	4	69·737	72 55 24·03	16·933	0·251	5	69·583
304	„ 19522	7	9 52 13·44	3·356	0·016	5	70·823	68 3 33·43	17·016	0·254	5	70·823
305	„ 19568	7½	9 54 31·33	3·508	0·026	5	69·605	57 50 34·93	17·124	0·269	5	69·605
306	„ 19613	7½	9 56 23·59	3·525	0·028	4	73·493	56 43 34·19	17·203	0·266	4	73·493
307	„ 19606	7	9 56 37·76	3·981	0·056	4	70·983	37 0 1·03	17·216	0·294	4	70·983
308	„ 19635	7½	9 56 44·84	3·315	0·015	5	71·240	70 25 9·50	17·222	0·241	5	71·240
309	„ 19735	6½	10 0 37·07	3·259	0·013	5	71·636	74 12 21·39	17·393	0·231	5	71·636
310	„ 19743	7	10 0 52·08	3·089	0·004	5	70·628	88 26 52·52	17·404	0·219	5	70·628
311	„ 19782	7	10 2 41·68	3·105	0·005	5	71·429	86 59 32·93	17·486	0·220	5	72·047
312	„ 19808	7	10 3 56·47	3·324	0·015	5	70·225	68 39 37·26	17·535	0·230	5	70·225
313	„ 19833	7	10 4 52·82	3·315	0·016	5	70·831	69 14 28·80	17·575	0·227	5	70·831
314	„ 19865	6	10 6 28·70	3·406	0·020	4	72·234	62 13 18·39	17·643	0·233	3	71·908
315	„ 19886	7½	10 7 35·22	3·648	0·038	5	70·238	47 28 49·34	17·689	0·249	4	70·500
316	„ 20076	6½	10 14 11·88	3·022	0·002	6	70·943	94 43 45·50	17·954	0·191	4	71·275
317	„ 20112	7½	10 15 53·73	3·282	0·014	5	74·882	70 12 50·96	18·019	0·204	5	74·882
318	„ 20169	7	10 17 57·68	3·503	0·029	5	71·477	53 8 12·07	18·097	0·214	5	71·477
319	„ 20202	7	10 19 2·26	3·341	0·018	4	74·537	64 37 30·24	18·138	0·203	4	74·537
320	„ 20296	7½	10 21 41·40	3·396	0·024	6	71·093	59 36 30·38	18·237	0·202	5	71·474

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321	LL 20301	7½	10 22 5·49	+3·655	−0·043	4	74·015	43 28 58·75	+18·251	+0·217	3	73·592
322	,, 20357	7½	10 23 39·42	3·145	0·007	4	71·495	82 16 32·44	18·307	0·181	4	71·495
323	,, 20453	7½	10 27 43·65	3·614	0·050	5	70·863	43 40 29·39	18·450	0·204	5	70·863
324	,, 20483	6	10 28 14·85	3·042	0·002	4	71·780	93 13 23·94	18·468	0·170	4	71·780
325	,, 20484	6	10 28 23·84	3·097	0·004	6	74·778	87 7 30·38	18·473	0·171	6	74·778
326	,, 20521	6½	10 29 49·34	2·981	+0·002	5	71·638	99 54 36·10	18·520	0·160	5	71·638
327	,, 20556	6	10 31 8·26	2·956	0·001	5	72·459	102 42 34·73	18·563	0·165	5	72·459
328	,, 20566	7½	10 31 41·26	3·129	−0·006	4	75·291	83 24 41·40	18·583	0·167	4	75·291
329	,, 20596	7½	10 33 11·21	3·519	0·035	4	71·499	47 47 46·42	18·631	0·186	4	71·499
330	,, 20623	7½	10 34 22·54	3·261	0·015	5	71·868	68 46 8·43	18·669	0·167	5	71·868
331	,, 20642	7½	10 34 50·10	3·169	0·010	5	73·673	78 34 57·05	18·684	0·170	5	73·673
332	,, 20695	7½	10 37 11·26	3·502	0·035	4	71·253	47 36 15·58	18·758	0·176	4	71·253
333	,, 20748	6½	10 39 26·56	3·181	0·010	6	72·933	76 34 5·33	18·826	0·154	5	73·062
334	,, 20876	7	10 44 18·34	3·165	0·008	6	72·748	77 43 55·18	18·969	0·144	6	72·748
335	,, 20896	7½	10 45 13·19	3·419	0·030	5	69·876	50 58 27·10	18·995	0·156	5	69·876
336	,, 20937	7	10 47 26·93	3·318	0·021	5	72·866	59 40 37·58	19·029	0·147	5	72·866
337	,, 20988	9?	10 48 13·62	3·015	+0·002	4	71·492	97 41 13·42	19·077	0·127	4	71·492
338	,, 21030	7	10 49 46·78	3·113	−0·006	4	73·788	84 1 56·92	19·119	0·131	4	73·788
339	,, 21063	7½	10 51 24·16	3·143	0·007	6	72·596	79 36 14·86	19·162	0·130	6	72·596
340	,, 21277	7	10 59 59·98	3·205	0·014	3	75·290	68 48 52·54	19·369	0·114	4	75·294
341	,, 21266	7½	11 0 25·55	3·337	0·027	3	74·257	52 30 42·07	19·379	0·120	4	73·995
342	,, 21300	7	11 0 34·46	3·208	0·014	5	72·651	68 8 48·00	19·382	0·114	5	72·651
343	,, 21345	7½	11 2 50·69	3·287	0·023	5	73·083	56 45 52·87	19·433	0·113	4	74·034
344	,, 21411	7½	11 5 17·05	3·296	0·025	4	74·517	54 30 27·36	19·484	0·108	4	74·517
345	,, 21418	6½	11 5 27·28	3·304	0·027	7	71·549	53 28 28·85	19·488	0·109	5	72·061
346	,, 21491	7½	11 7 57·63	3·215	0·017	4	74·514	64 18 22·58	19·541	0·100	4	74·514
347	,, 21519	6½	11 9 8·02	3·009	+0·004	5	71·686	101 53 2·82	19·560	0·089	5	71·686
348	,, 21546	7½	11 10 49·71	3·208	−0·016	5	72·258	64 14 19·71	19·591	0·091	4	73·005
349	,, 21662	7½	11 15 52·66	3·234	0·021	5	73·489	57 27 31·45	19·682	0·084	4	73·790
350	,, 21727	6	11 18 20·10	3·065	0·000	4	70·765	91 29 49·42	19·723	0·076	3	71·290
351	,, 21757	6	11 19 27·48	3·231	0·023	5	72·889	55 50 8·30	19·740	0·077	5	72·889
352	,, 21824	7½	11 21 34·54	3·258	0·028	4	73·280	49 58 37·25	19·772	0·074	4	73·280
353	,, 21846	7	11 22 23·40	3·203	0·020	4	70·776	58 51 17·34	19·784	0·071	3	71·306
354	,, 21896	7½	11 25 1·47	3·166	0·014	4	71·783	64 58 17·08	19·820	0·064	4	71·783
355	,, 21977	7	11 28 16·61	3·142	0·012	5	71·282	68 50 24·88	19·860	0·056	5	71·282
356	,, 22098	7	11 33 3·06	3·047	+0·004	4	73·805	98 44 45·37	19·914	0·046	4	73·805
357	,, 22100	7	11 33 22·55	3·150	−0·002	5	72·306	65 34 19·12	19·918	0·047	4	71·817
358	,, 22144	6½	11 35 19·93	3·132	0·015	4	70·030	67 3 59·19	19·937	0·043	4	70·030
359	,, 22184	7	11 37 1·07	3·133	0·014	5	71·319	65 16 6·84	19·952	0·040	4	71·817
360	,, 22229	7½	11 38 45·90	3·165	0·023	4	70·030	53 23 6·37	19·965	0·040	3	70·283

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361	LL 22273	7½	11 40 34·13	+3·127	−0·010	5	72·301	64 51 11·71	+19·980	+0·031	4	73·057
362	„ 22350	7½	11 43 59·67	3·122	0·017	4	74·806	61 10 51·09	20·004	0·026	4	74·806
363	„ 22354	7	11 44 12·20	3·134	0·020	4	73·535	55 40 23·13	20·007	0·029	4	73·535
364	„ 22359	7	11 44 23·76	3·132	0·021	6	70·642	55 54 10·33	20·007	0·026	6	70·642
365	„ 22436	7½	11 47 52·90	3·090	0·007	4	73·777	75 7 19·76	20·025	0·018	4	73·777
366	„ 22450	6½	11 48 30·30	3·122	0·022	4	72·797	52 31 8·60	20·027	0·016	4	72·797
367	„ 22484	7½	11 49 32·96	3·106	0·016	5	70·923	60 25 6·56	20·032	0·014	5	70·923
368	„ 22532	7½	11 51 22·19	3·095	0·014	5	72·497	64 8 19·23	20·038	0·010	4	73·291
369	„ 22541	7½	11 51 45·85	3·102	0·019	5	71·078	57 21 16·99	20·038	0·007	5	71·078
370	„ 22562	7	11 52 54·92	3·070	+0·002	4	75·066	91 11 39·17	20·044	0·008	4	75·066
371	„ 22567	6½	11 53 16·40	3·098	−0·020	4	70·576	55 14 34·02	20·044	0·007	4	70·576
372	„ 22612	5½	11 54 59·80	3·093	0·023	5	70·689	53 13 52·24	20·048	0·004	5	70·689
373	„ 22634	7½	11 55 55·53	3·075	0·003	4	74·570	81 12 21·10	20·050	0·004	4	74·570
374	„ 22663	7	11 57 57·19	3·072	0·000	5	74·083	86 6 49·81	20·051	−0·003	5	74·083
375	„ 22683	7	11 58 1·71	3·079	0·021	4	70·561	53 42 31·14	20·052	0·001	4	70·561
376	„ 22697	7	11 58 29·37	3·077	0·019	4	73·066	55 31 27·74	20·052	0·003	4	73·066
377	„ 22755	7	12 0 53·89	3·071	0·001	4	70·809	84 45 45·77	20·054	0·005	4	70·809
378	„ 22764	7	12 1 28·58	3·066	0·016	5	71·297	58 13 32·25	20·052	0·010	5	71·297
379	„ 22846	6½	12 4 13·05	3·050	0·023	4	74·562	49 23 5·82	20·050	0·013	4	74·562
380	„ 22880	7	12 5 24·41	3·054	0·014	4	71·295	60 44 17·37	20·048	0·017	4	71·307
381	„ 22902	7½	12 6 16·59	3·048	0·016	4	72·307	57 28 45·91	20·045	0·018	4	72·307
382	„ 23002	7½	12 10 11·16	3·021	0·022	5	71·111	49 41 6·52	20·033	0·026	4	71·322
383	„ 23018	5½	12 10 57·38	3·035	0·015	4	75·078	60 20 29·70	20·030	0·027	4	75·078
384	„ 23159	6½	12 15 32·77	2·971	0·029	6	72·643	42 5 44·55	20·007	0·036	5	73·308
385	„ 23195	7½	12 16 57·37	3·024	0·011	6	69·628	64 41 6·06	19·997	0·040	6	69·628
386	„ 23225	7½	12 18 19·96	3·005	0·014	4	75·328	58 14 44·40	19·989	0·041	4	75·328
387	„ 23252	6	12 19 22·33	3·066	+0·001	5	70·715	87 14 16·11	19·981	0·044	5	70·715
388	„ 23287	7½	12 20 46·10	2·980	−0·017	4	71·065	52 54 17·38	19·970	0·047	5	71·319
389	„ 23312	6½	12 21 15·21	3·087	+0·005	5	73·120	97 57 26·92	19·966	0·048	5	73·120
390	„ 23334	6	12 22 8·33	3·006	−0·013	4	74·819	63 3 13·05	19·962	0·040	4	74·819
391	„ 23354	7	12 22 50·42	2·976	0·017	5	69·494	54 34 41·26	19·953	0·050	5	69·494
392	„ 23381	6	12 23 56·58	3·061	+0·001	6	73·008	85 46 23·53	19·943	0·053	6	73·008
393	„ 23422	7½	12 25 4·94	2·994	−0·011	5	73·730	62 12 56·74	19·933	0·054	5	73·730
394	„ 23433	7½	12 25 24·52	3·074	+0·004	3	70·290	91 3 19·74	19·931	0·054	3	70·290
395	„ 23453	7½	12 26 15·38	3·003	−0·009	5	69·313	65 51 47·97	19·922	0·056	4	69·319
396	„ 23487	5½	12 27 14·39	2·964	0·015	5	72·129	56 2 3·01	19·911	0·059	5	72·129
397	„ 23500	7	12 27 46·08	3·039	0·002	6	73·489	78 21 35·18	19·906	0·060	5	72·921
398	„ 23570	7½	12 29 39·49	2·889	0·024	7	69·454	43 30 12·26	19·885	0·061	5	69·516
399	„ 23584	6½	12 30 25·06	3·079	+0·009	5	70·722	91 36 1·11	19·877	0·066	5	70·722
400	„ 23608	5½	12 31 26·72	3·058	0·002	6	74·496	86 0 5·92	19·864	0·067	6	74·496

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401	LL 23626	6½	12 32 17·40	+3·071	+ 0·003	4	72·564	90 8 21·94	+ 19·853	− 0·070	4	72·564
402	,, 23740	7	12 37 13·08	2·964	− 0·010	4	74·837	63 36 28·82	19·789	0·077	3	74·339
403	,, 23755	6	12 37 51·61	2·909	0·015	5	70·506	53 31 11·34	19·780	0·076	5	70·506
404	,, 23753	6½	12 37 53·74	3·139	+ 0·014	4	72·333	107 3 54·63	19·779	0·081	4	72·333
405	,, 23802	7	12 39 25·87	2·915	− 0·014	5	73·934	55 44 44·66	19·756	0·080	5	73·934
406	,, 23838	7	12 40 40·45	3·002	0·004	4	71·323	73 41 50·41	19·738	0·083	5	71·720
407	,, 23858	7½	12 41 22·01	2·985	0·006	4	70·559	70 15 56·61	19·727	0·084	5	70·914
408	,, 23900	6	12 42 26·87	2·953	0·008	4	70·578	64 26 46·80	19·709	0·086	4	70·578
409	,, 23902	7	12 42 49·94	3·046	0·001	4	75·837	84 6 59·59	19·704	0·090	4	75·837
410	,, 23954	7½	12 44 46·68	3·030	+ 0·000	6	70·479	81 4 54·33	19·671	0·093	5	70·718
411	,, 23967	7½	12 45 12·21	3·067	0·003	6	73·166	89 12 22·59	19·664	0·093	6	73·166
412	,, 23980	7½	12 45 32·47	2·940	− 0·008	5	70·119	63 37 3·95	19·658	0·091	5	70·119
413	,, 23999	7	12 46 20·56	3·139	+ 0·012	4	74·333	104 15 36·20	19·644	0·097	4	74·333
414	,, 24155	7	12 51 58·45	3·082	0·005	5	72·738	92 12 1·48	19·540	0·106	5	72·738
415	,, 24173	6½	12 52 17·94	2·903	− 0·010	5	69·699	60 58 38·44	19·533	0·101	5	69·699
416	,, 24164	7½	12 52 19·41	3·078	+ 0·005	5	74·331	91 22 37·41	19·532	0·109	5	74·331
417	,, 24243	6	12 55 13·18	2·944	− 0·008	5	72·728	68 1 47·79	19·480	0·101	5	72·728
418	,, 24247	7½	12 55 15·19	2·815	0·015	5	69·699	51 15 3·95	19·475	0·101	5	69·699
419	,, 24265	7	12 56 11·12	2·922	0·011	5	72·722	65 48 7·82	19·454	0·109	5	72·722
420	,, 24294	7½	12 57 11·56	3·085	+ 0·006	4	75·358	92 31 6·09	19·432	0·116	4	75·358
421	,, 24306	7	12 57 58·88	3·071	0·005	4	74·078	90 1 46·53	19·414	0·119	4	74·078
422	,, 24333	7½	12 59 6·85	2·986	− 0·002	5	73·311	76 4 36·80	19·389	0·119	5	73·311
423	,, 24373	7½	13 0 58·49	3·058	+ 0·004	5	74·330	87 49 45·83	19·347	0·123	5	74·330
424	,, 24499	7½	13 4 42·18	2·810	− 0·011	4	74·333	55 0 21·73	19·258	0·121	4	74·333
425	,, 24508	6½	13 5 14·01	2·915	0·005	4	76·352	67 23 19·84	19·245	0·127	4	76·352
426	,, 24519	7	13 6 3·82	3·081	+ 0·006	4	74·340	91 34 28·91	19·225	0·134	4	74·340
427	,, 24586	5½	13 8 2·22	2·988	− 0·000	4	76·352	77 58 39·73	19·176	0·133	4	76·352
428	,, 24711	7½	13 12 25·96	2·859	0·007	5	71·738	62 56 58·20	19·060	0·136	6	72·012
429	,, 24778	6½	13 15 16·93	2·728	0·012	5	74·947	51 27 39·58	18·982	0·134	5	74·947
430	,, 24794	7½	13 15 46·36	2·853	0·006	5	69·715	63 19 14·43	18·978	0·126	5	69·715
431	,, 24803	6½	13 16 10·11	2·809	0·008	4	71·845	59 1 34·81	18·955	0·141	4	71·845
432	,, 24917	7½	13 21 39·94	3·047	+ 0·005	5	75·566	87 5 21·20	18·793	0·160	4	75·364
433	,, 24942	7	13 22 39·01	3·033	0·004	5	72·941	85 27 17·42	18·769	0·154	5	72·941
434	,, 24963	7	13 23 9·69	3·056	0·005	4	74·594	88 13 42·03	18·747	0·164	4	74·594
435	,, 25057	6½	13 26 38·57	2·842	− 0·007	5	73·736	64 58 39·19	18·640	0·151	5	73·736
436	,, 25177	7	13 31 7·94	3·043	+ 0·005	5	74·152	86 57 14·82	18·489	0·176	5	74·152
437	,, 25259	6	13 34 20·25	2·741	− 0·007	4	72·118	58 19 54·53	18.377	0·167	5	72·165
438	,, 25288	6	13 35 47·68	2·984	+ 0·002	4	73·574	80 57 5·27	18·325	0·183	5	73·535
439	,, 25363	7½	13 38 48·52	2·963	0·002	4	74·108	79 1 12·18	18·217	0·187	4	74·108
440	,, 25380	7	13 39 35·37	3·014	0·005	5	75·368	84 13 51·67	18·189	0·190	5	75·368

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441	LL 25395	7½	13 39 47·25	+2·672	—0·007	6	71·494	54 41 58·93	+18·183	—0·170	4	72·574
442	,, 25522	7	13 45 20·20	2·649	0·007	4	74·122	54 34 57·29	17·972	0·179	4	74·122
443	,, 25525	5½	13 45 24·88	2·650	0·009	4	72·595	54 41 20·87	17·972	0·177	5	72·547
444	,, 25646	7½	13 50 10·93	2·724	0·004	4	70·594	60 41 26·16	17·779	0·190	5	70·945
445	,, 25645	6½	13 50 11·55	2·762	0·003	5	75·366	63 26 37·38	17·779	0·193	5	75·366
446	,, 25723	7½	13 53 45·24	3·034	+ 0·006	5	74·354	86 41 35·52	17·636	0·211	5	74·354
447	,, 25836	7	13 57 36·19	2·933	0·002	4	72·621	78 5 28·36	17·470	0·216	5	72·568
448	,, 25898	7½	14 0 23·74	2·846	0·000	5	74·763	71 27 58·74	17·349	0·214	5	74·763
449	,, 26017	6	14 4 55·40	3·047	0·007	4	71·878	88 1 31·56	17·146	0·236	5	71·973
450	,, 26034	7½	14 5 16·97	2·628	− 0·004	4	72·857	57 30 45·84	17·130	0·204	5	72·857
451	,, 26056	6	14 6 58·75	3·074	+ 0·008	4	75·895	90 13 51·02	17·054	0·240	4	75·895
452	,, 26122	7½	14 9 4·40	2·749	− 0·002	4	73·404	65 42 22·72	16·956	0·220	4	73·404
453	,, 26143	6	14 10 30·31	2·798	0·000	4	74·864	69 16 14·31	16·887	0·227	4	74·864
454	,, 26186	6½	14 12 19·16	2·778	− 0·001	6	72·557	68 5 37·04	16·801	0·229	5	73·198
455	,, 26200	6	14 13 2·97	3·058	+ 0·008	5	73·966	89 0 56·06	16·767	0·250	5	73·966
456	,, 26272	7½	14 15 24·94	2·510	− 0·004	5	72·579	53 0 40·57	16·656	0·206	5	72·579
457	,, 26273	6½	14 16 6·84	3·072	+ 0·008	5	73·384	90 2 33·53	16·620	0·297	5	73·384
458	,, 26356	7	14 19 18·98	3·050	0·008	5	73·784	88 25 4·59	16·460	0·259	5	73·784
459	,, 26391	6½	14 20 6·43	2·682	− 0·001	7	73·239	63 8 45·70	16·422	0·228	8	73·129
460	,, 26474	6	14 22 53·34	2·487	0·005	4	75·912	53 13 14·28	16·278	0·211	4	75·912
461	,, 26468	7	14 22 58·43	2·768	+ 0·004	4	74·866	68 39 6·25	16·276	0·245	4	74·866
462	,, 26492	6	14 24 15·11	2·997	0·006	5	73·603	84 38 54·22	16·211	0·263	5	73·603
463	,, 26594	7½	14 28 34·86	2·922	0·004	5	72·595	79 32 35·14	15·986	0·260	5	72·595
464	,, 26616	7½	14 28 45·64	2·405	− 0·003	4	75·910	50 29 21·72	15·974	0·220	4	75·910
465	,, 26670	7½	14 31 4·22	2·689	0·000	4	73·886	64 58 13·61	15·852	0·246	4	73·886
466	,, 26695	7	14 31 48·89	2·463	0·002	4	75·408	53 30 17·59	15·814	0·224	4	75·408
467	,, 26731	5	14 33 19·46	2·265	0·002	4	71·134	45 47 45·28	15·730	0·210	4	71·134
468	,, 26747	6	14 34 27·73	2·725	+ 0·002	5	72·995	67 27 57·35	15·681	0·236	5	72·995
469	,, 26826	6	14 37 20·45	3·186	0·011	5	70·770	97 42 7·01	15·511	0·296	5	70·770
470	,, 26851	6	14 37 23·83	2·425	− 0·004	5	74·213	52 41 19·46	15·505	0·223	5	73·601
471	,, 26957	7½	14 41 48·05	3·171	+ 0·011	5	73·997	96 33 47·48	15·259	0·304	5	73·997
472	,, 27120	7½	14 46 42·24	2·669	0·001	5	70·377	65 39 54·30	14·976	0·267	5	70·377
473	,, 27114	7½	14 46 49·59	2·822	0·004	5	73·201	74 19 59·60	14·971	0·278	5	73·201
474	,, 27324	7	14 53 2·45	2·155	0·000	5	75·206	45 0 41·59	14·604	0·221	5	75·206
475	,, 27325	7½	14 53 50·82	2·819	0·004	5	71·578	74 38 52·03	14·555	0·287	5	71·578
476	,, 27358	7	14 54 26·85	2·293	0·000	4	71·374	49 50 14·64	14·520	0·236	4	71·373
477	,, 27403	7½	14 56 45·52	3·048	0·007	4	75·146	88 35 52·96	14·379	0·313	4	75·146
478	,, 27509	7	14 59 43·99	2·302	− 0·002	4	72·409	50 53 20·72	14·196	0·241	4	72·409
479	,, 27507	6½	15 0 33·01	3·024	+ 0·008	4	73·885	87 8 2·02	14·146	0·310	4	73·885
480	,, 27575	6½	15 1 29·31	2·355	− 0·003	4	75·416	53 2 33·94	14·087	0·244	4	75·416

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481	G 2194	6½	15 4 12·00	+1·901	+0·006	5	70·175	39 26 49·32	+13·912	−0·177	5	70·175
482	LL 27705	7	15 5 41·51	2·708	0·003	4	73·912	69 27 49·32	13·823	0·291	4	73·912
483	„ 27718	6½	15 6 9·36	2·728	0·003	5	72·589	70 31 58·78	13·793	0·289	5	72·589
484	„ 27763	6	15 7 59·58	3·157	0·010	5	74·618	95 1 2·65	13·676	0·336	5	74·618
485	„ 27822	6	15 8 31·09	1·941	0·003	4	74·913	40 55 58·45	13·643	0·213	4	74·913
486	„ 27813	7	15 9 19·10	2·887	0·005	5	71·185	79 23 21·56	13·592	0·309	5	71·185
487	„ 27942	7½	15 12 38·71	2·465	0·002	5	73·602	58 41 16·76	13·377	0·266	5	73·602
488	„ 27943	6	15 12 46·75	2·556	0·002	4	70·139	62 41 10·11	13·367	0·286	4	70·139
489	„ 27950	6½	15 13 45·58	3·152	0·010	4	70·865	94 38 49·44	13·304	0·347	4	70·865
490	„ 27976	7	15 14 8·42	2·771	0·003	5	74·818	73 20 29·67	13·279	0·301	6	73·915
491	„ 28028	7½	15 15 33·97	2·443	0·001	5	71·395	58 3 19·54	13·184	0·271	5	71·395
492	„ 28083	6½	15 17 17·88	2·519	0·001	5	71·174	61 28 39·64	13·070	0·277	5	71·174
493	„ 28118	7	15 19 3·22	3·085	0·009	4	73·164	90 47 39·48	12·954	0·346	4	73·164
494	„ 28164	6	15 19 42·16	2·022	0·002	5	69·772	44 16 6·07	12·900	0·245	5	69·772
495	„ 28152	6	15 20 2·45	2·699	0·004	5	74·208	70 3 40·02	12·888	0·300	5	74·208
496	„ 28157	7½	15 20 39·06	3·224	0·012	4	72·417	98 29 36·08	12·844	0·366	4	72·417
497	„ 28211	6, 7	15 22 3·47	2·577	0·004	5	73·226	64 26 40·51	12·751	0·295	5	73·226
498	„ 28244	7	15 23 14·47	2·530	0·003	4	76·423	62 24 46·31	12·671	0·291	4	76·423
499	„ 28271	7½	15 24 15·72	2·602	0·003	4	71·154	65 44 4·67	12·601	0·301	4	71·154
500	„ 28318	6	15 25 32·10	2·277	0·001	4	76·172	52 45 3·58	12·515	0·264	4	76·172
501	„ 28347	6	15 26 25·59	2·298	0·029	6	71·061	52 56 20·75	12·460	0·258	5	70·896
502	„ 28496	6	15 31 0·71	2·215	0·002	4	74·173	51 11 38·80	12·136	0·264	4	74·173
503	„ 28514	7½	15 32 9·91	2·642	0·003	4	72·667	68 7 55·27	12·058	0·311	4	72·667
504	„ 28573	6½	15 34 1·68	2·831	0·001	4	71·147	77 31 27·31	11·928	0·331	3	71·057
505	„ 28553	6½	15 34 1·90	3·330	0·013	4	75·180	103 32 56·00	11·926	0·393	4	75·180
506	„ 28589	7½	15 34 37·47	2·698	0·003	4	75·677	70 54 27·10	11·883	0·323	4	75·677
507	„ 28716	6	15 38 57·94	2·959	0·007	5	73·220	84 8 34·34	11·576	0·355	5	73·220
508	„ 28737	7	15 39 50·08	2·946	0·006	5	76·033	83 28 51·94	11·514	0·354	5	76·033
509	„ 28780	6	15 42 26·36	3·419	0·014	4	71·896	107 30 9·96	11·337	0·400	4	71·896
510	„ 28910	7	15 46 1·97	2·759	0·004	5	71·407	74 22 5·56	11·060	0·347	5	71·407
511	„ 28980	6	15 49 14·65	3·361	0·013	5	71·198	104 26 48·18	10·830	0·416	5	71·198
512	„ 29070	7½	15 52 7·94	3·124	0·008	5	72·829	92 42 4·38	10·615	0·390	5	72·829
513	„ 29226	6½	15 56 18·08	2·124	0·003	5	70·604	50 27 25·00	10·306	0·268	5	70·604
514	„ 29341	7	15 59 17·41	2·276	0·004	5	74·239	55 27 52·94	10·080	0·289	5	74·239
515	„ 29349	7	16 0 0·34	2·597	0·003	5	70·399	67 44 58·30	10·028	0·330	5	70·399
516	„ 29440	5½	16 3 2·42	3·133	0·008	4	74·169	93 7 21·42	9·796	0·400	4	74·169
517	„ 29545	7	16 6 31·21	3·073	0·004	5	71·213	90 11 1·46	9·529	0·396	5	71·213
518	„ 29656	7½	16 9 54·54	3·178	0·009	5	75·650	95 10 18·30	9·268	0·413	5	75·650
519	„ 29706	7½	16 12 11·74	3·208	0·008	4	71·195	96 33 18·47	9·089	0·420	4	71·195
520	„ 29777	6	16 14 25·89	2·600	0·001	4	72·413	68 33 6·96	8·912	0·339	4	72·413

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521	LL 29800	6	16 15 54·23	+3·108	+0·007	4	72·442	91 46 18·50	+8·796	−0·411	4	72·442
522	„ 29915	6½	16 19 49·27	3·012	0·007	5	72·844	87 11 44·89	8·489	0·401	5	72·844
523	„ 30073	7½	16 25 14·60	2·886	0·005	5	75·266	81 25 35·38	8·058	0·388	5	75·266
524	„ 30076	7½	16 25 56·67	3·343	0·010	4	71·910	102 31 11·52	8·002	0·447	4	71·910
525	„ 30187	6	16 27 52·34	1·803	0·007	4	75·469	44 7 30·73	7·847	0·243	4	75·469
526	„ 30174	7½	16 29 27·23	3·366	0·010	4	72·475	103 27 7·66	7·721	0·450	4	72·475
527	„ 30271	7	16 31 23·87	2·320	0·003	5	76·064	58 46 35·84	7·561	0·316	5	76·064
528	„ 30256	6	16 31 44·07	3·251	0·009	4	72·711	98 21 25·27	7·534	0·440	4	72·711
529	„ 30280	7½	16 32 2·72	2·624	0·003	4	72·978	70 10 51·75	7·508	0·360	4	72·978
530	„ 30345	7½	16 34 31·22	3·157	0·007	5	74·672	93 57 44·96	7·307	0·430	5	74·672
531	„ 30464	7½	16 38 10·23	3·015	0·005	5	74·658	87 25 20·75	7·009	0·413	5	74·658
532	„ 30496	6½	16 38 42·77	2·519	0·004	5	71·679	66 14 23·37	6·965	0·346	5	71·679
533	19 Ophiuchi	6	16 40 36·61	3·020	0·004	5	70·058	87 41 54·20	6·807	0·414	5	70·058
534	LL 30568	6½	16 41 59·32	3·165	0·007	5	73·859	94 16 52·59	6·713	0·411	4	73·948
535	„ 30590	6½	16 42 9·40	2·761	0·004	5	71·677	76 10 36·35	6·681	0·381	5	71·677
536	„ 30649	7	16 44 3·80	2·718	0·004	4	73·467	74 23 43·97	6·521	0·380	4	73·467
537	„ 30671	7	16 45 36·61	3·180	0·006	5	73·269	94 55 46·24	6·395	0·441	5	73·269
538	„ 30694	6½	16 46 25·68	3·065	0·006	5	71·676	89 45 19·51	6·322	0·427	5	71·676
539	„ 30734	7	16 46 41·57	2·371	0·003	4	75·220	61 6 53·68	6·306	0·330	4	75·220
540	„ 30769	7	16 48 11·14	2·573	0·004	5	74·668	68 36 47·18	6·183	0·358	5	74·668
541	„ 30800	5½	16 49 18·99	2·578	0·004	4	70·439	68 49 50·20	6·088	0·360	5	70·439
542	„ 30812	7½	16 49 38·59	2·492	0·005	5	74·673	65 33 37·36	6·060	0·350	5	74·673
543	„ 30864	6	16 51 34·88	2·750	0·003	4	71·453	75 54 52·10	5·898	0·384	4	71·453
544	„ 30962	6½	16 53 18·43	1·358	0·009	4	73·245	37 5 54·06	5·754	0·193	4	73·245
545	„ 30923	7½	16 53 50·10	2·845	0·004	5	71·723	80 0 17·84	5·700	0·414	4	71·723
546	„ 30930	6½	16 54 9·12	2·917	0·003	4	71·197	83 13 8·74	5·688	0·408	4	71·197
547	„ 30990	5½	16 55 28·80	2·530	0·004	4	74·728	67 10 28·61	5·571	0·357	4	74·728
548	„ 31022	7	16 57 1·87	3·070	0·006	4	71·217	89 57 33·63	5·440	0·431	4	71·217
549	„ 31099	7	16 58 41·84	2·183	0·004	5	75·100	55 25 56·87	5·299	0·310	5	75·100
550	„ 31171	6	17 2 4·27	3·155	0·005	4	69·480	93 42 22·01	5·014	0·447	4	69·480
551	„ 31213	7½	17 2 19·73	2·374	0·003	5	73·282	61 42 25·37	4·993	0·337	5	73·282
552	„ 31292	7	17 4 49·01	2·211	0·004	5	73·664	56 28 17·27	4·779	0·314	5	73·664
553	„ 31313	5	17 5 20·42	1·944	0·004	5	70·464	49 3 31·71	4·725	0·296	5	70·464
554	„ 31349	7½	17 7 48·19	2·458	0·002	5	70·465	64 51 30·21	4·529	0·350	5	70·465
555	„ 31406	7	17 9 49·70	2·647	0·004	5	73·701	72 1 13·45	4·355	0·377	5	73·701
556	„ 31428	7	17 10 47·33	2·642	0·003	4	76·486	71 50 3·33	4·273	0·379	4	76·486
557	„ 31434	7	17 11 10·69	2·762	0·004	5	72·698	76 43 11·00	4·239	0·396	5	72·698
558	„ 31494	7	17 13 13·18	3·019	0·004	5	71·318	87 43 28·38	4·064	0·433	5	71·318
559	„ 31523	7	17 13 13·30	2·434	0·003	5	75·277	64 3 20·41	4·066	0·348	5	75·277
560	„ 31547	7	17 14 10·17	2·695	0·004	5	72·512	73 58 50·90	3·985	0·384	5	72·512

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561	LL 31693	7	17 17 3·09	+1·596	+0·006	5	71·889	41 40 53·93	+3·738	−0·230	5	71·889
562	„ 31741	6	17 20 2·50	2·892	0·002	5	70·089	82 17 17·92	3·477	0·415	5	70·089
563	„ 31754	6	17 20 7·42	2·668	0·004	5	72·521	72 58 1·69	3·471	0·386	5	72·521
564	„ 31864	7	17 20 21·95	0·146	0·017	4	71·510	24 14 8·74	3·454	0·017	4	71·510
565	„ 31816	6½	17 22 50·37	3·205	0·005	4	73·026	95 48 40·99	3·210	0·501	4	73·026
566	„ 31849	6½	17 23 27·51	3·169	0·005	5	72·300	94 15 54·61	3·184	0·456	5	72·300
567	„ 31921	7½	17 24 49·10	2·534	0·002	5	75·686	67 51 47·97	3·068	0·364	5	75·686
568	„ 32075	7½	17 29 7·34	2·156	0·003	4	75·495	55 22 6·06	2·694	0·311	4	75·495
569	„ 32165	6½	17 31 14·17	2·057	0·004	5	72·510	52 36 54·03	2·511	0·297	5	72·510
570	„ 32255	5½	17 33 13·73	1·561	0·001	5	70·859	41 20 14·99	2·357	0·226	5	70·859
571	„ 32256	7½	17 34 1·06	2·214	0·004	5	69·509	57 11 9·15	2·268	0·321	5	69·500
572	„ 32267	7½	17 34 17·38	2·294	0·003	5	72·909	59 40 18·34	2·245	0·333	5	72·909
573	„ 32294	6½	17 35 18·67	2·709	0·002	5	75·317	74 45 11·02	2·157	0·394	5	75·317
574	„ 32333	6½	17 36 16·32	2·545	0·003	5	71·273	68 25 40·72	2·074	0·370	5	71·273
575	„ 32408	6	17 38 22·22	2·728	0·002	4	69·512	75 31 52·98	1·893	0·393	4	69·512
576	„ 32456	6	17 38 23·04	1·375	0·004	5	71·499	38 7 5·52	1·889	0·200	5	71·499
577	„ 32422	7½	17 39 28·19	3·256	0·003	5	72·533	97 55 36·26	1·797	0·470	5	72·533
578	„ 32505	6	17 40 46·78	2·253	0·003	4	72·492	58 26 32·20	1·681	0·327	4	72·492
579	„ 32509	7	17 41 50·74	3·121	0·003	4	72·015	92 8 58·73	1·588	0·453	4	72·015
580	„ 32601	6½	17 44 0·23	2·838	0·001	5	72·112	80 6 33·73	1·397	0·413	5	72·112
581	„ 32633	6½	17 45 16·10	3·099	0·002	4	71·004	91 12 3·46	1·288	0·451	4	71·004
582	„ 32779	6	17 47 22·78	1·739	0·003	5	72·133	45 3 30·02	1·106	0·253	5	72·133
583	„ 32849	7½	17 50 5·06	2·745	0·002	4	71·774	76 17 44·57	0·868	0·400	5	71·330
584	„ 32880	7½	17 50 48·14	2·587	0·003	4	74·528	70 5 26·15	0·805	0·377	5	74·124
585	„ 32935	5?	17 51 47·5	2·054	0·002	4	72·523	52 43 50·66	0·717	0·300	4	72·523
586	„ 32921	6½	17 51 52·20	2·476	0·003	5	69·893	65 59 22·19	0·713	0·360	5	69·893
587	„ 33041	6	17 55 5·03	2·710	0·002	4	69·725	74 53 47·73	0·431	0·394	4	69·725
588	„ 33131	5	17 56 50·17	2·193	0·002	5	71·749	56 41 13·15	0·277	0·317	5	71·749
589	„ 33112	7½	17 56 56·03	2·667	0·002	5	71·079	73 11 18·35	0·268	0·388	5	71·079
590	„ 33183	6½	17 59 26·60	3·082	0·002	5	70·314	90 27 15·59	0·050	0·450	5	70·314
591	„ 33241	7	18 0 37·98	2·862	0·002	5	71·938	81 7 50·03	—0·055	0·417	5	71·938
592	„ 33376	6	18 4 10·43	2·994	0·001	5	70·681	86 41 56·26	0·393	0·476	5	70·681
593	„ 33493	7½	18 7 6·08	3·056	0·001	4	71·530	89 20 52·32	0·622	0·446	4	71·530
594	„ 33543	6	18 7 45·91	2·534	0·000	5	70·296	68 9 17·35	0·682	0·374	5	70·296
595	„ 33618	6	18 8 44·64	1·999	0·002	5	70·888	51 15 41·17	0·765	0·291	5	70·888
596	„ 33683	7½	18 11 21·74	3·103	0·001	5	70·638	91 22 36·36	0·994	0·454	5	70·638
597	„ 33773	6	18 12 4·18	1·613	0·002	4	72·553	42 28 55·05	1·056	0·234	4	72·553
598	„ 33719	6	18 12 5·87	2·745	0·001	3	71·223	76 16 14·31	1·058	0·398	4	70·549
599	„ 33847	7	18 15 40·33	3·100	0·001	5	70·929	91 15 42·91	1·404	0·562	5	70·929
600	„ 33896	6½	18 16 8·90	2·450	0·002	4	69·523	65 0 10·58	1·412	0·357	4	69·523

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601	LL 33959	6½	18 18 12·62	+3·110	+0·001	4	70·452	91 38 49·49	−1·591	−0·450	5	70·261
602	,, 34021	6	18 19 23·42	2·885	0·001	4	71·288	82 2 19·98	1·694	0·417	5	71·345
603	,, 34066	7½	18 20 9·99	2·697	0·001	5	70·522	74 18 44·57	1·761	0·390	5	70·522
604	,, 34128	5½	18 21 37·72	2·928	0·001	4	69·976	83 52 59·33	1·880	0·410	4	69·976
605	,, 34178	6	18 23 17·33	3·206	0·000	4	71·506	95 48 29·31	2·034	0·466	5	71·519
606	,, 34218	6	18 24 13·05	3·326	—0·001	5	70·047	100 52 57·77	2·115	0·481	5	70·047
607	,, 34319	6½	18 26 11·78	2·749	+0·001	6	71·552	76 21 35·30	2·285	0·399	4	71·751
608	,, 34350	6	18 27 8·61	2·880	0·006	5	72·549	81 49 37·37	2·369	0·416	5	72·549
609	,, 34424	6½	18 28 40·73	2·818	0·001	4	69·519	79 12 28·63	2·512	0·421	4	69·519
610	,, 34485	7	18 29 26·67	2·165	0·001	4	72·091	55 39 6·29	2·570	0·313	4	72·091
611	,, 34497	7	18 29 46·65	2·167	0·002	5	72·147	55 41 32·43	2·597	0·313	5	72·147
612	,, 34536	6	18 31 7·17	2·536	0·001	4	70·452	67 59 54·66	2·715	0·366	5	70·471
613	,, 34632	6½	18 34 9·55	2·867	0·001	4	70·241	81 14 53·96	2·977	0·411	5	70·302
614	,, 34636	7	18 34 15·78	2·791	0·001	6	72·062	78 3 46·21	2·986	0·401	6	72·062
615	,, 34700	7	18 35 16·39	2·044	0·002	5	71·148	52 7 37·08	3·075	0·294	5	71·148
616	,, 34664	6	18 35 35·21	3·238	—0·000	3	70·230	97 11 46·52	3·089	0·447	3	70·230
617	,, 34754	6½	18 36 46·66	2·262	+0·002	5	71·571	58 30 21·04	3·205	0·326	5	71·571
618	,, 34777	7½	18 37 53·09	2·790	0·001	4	71·006	77 57 32·48	3·300	0·401	5	71·321
619	,, 34779	7	18 38 14·91	3·083	—0·001	4	70·547	90 30 12·02	3·331	0·441	4	70·547
620	,, 34853	5½	18 38 58·37	2·254	+0·001	3	70·909	58 11 57·12	3·395	0·323	4	70·819
621	,, 34890	6	18 40 4·58	2·543	0·002	5	70·313	68 8 59·65	3·489	0·364	5	70·313
622	,, 35005	6½	18 42 59·65	3·055	0·000	4	70·235	89 18 30·34	3·741	0·439	4	70·235
623	,, 35028	6½	18 43 15·67	2·731	0·001	4	71·854	75 29 12·42	3·762	0·390	5	72·010
624	,, 35189	6	18 46 29·15	2·356	0·002	4	71·048	61 22 12·85	4·040	0·336	5	70·956
625	,, 35222	6½	18 47 2·33	2·107	0·001	5	72·609	53 36 55·92	4·087	0·300	5	72·609
626	,, 35297	5½	18 49 3·10	2·384	0·001	4	71·116	62 14 57·83	4·259	0·337	4	71·116
627	,, 35334	4½	18 49 45·24	2·979	0·000	4	70·312	85 57 47·89	4·319	0·423	4	70·312
628	,, 35332	7½	18 49 54·52	2·288	0·003	5	71·156	59 1 0·48	4·332	0·318	5	71·156
629	,, 35416	7½	18 51 27·85	1·902	0·001	5	72·175	48 6 31·64	4·464	0·267	5	72·175
630	,, 35395	6	18 52 2·25	2·932	0·001	5	70·306	83 55 44·48	4·514	0·414	6	70·346
631	,, 35421	6	18 52 27·53	2·668	0·000	5	70·803	72 48 42·99	4·550	0·377	5	70·803
632	,, 35445	6½	18 53 5·84	2·607	0·002	5	73·410	70 22 49·22	4·604	0·368	5	73·410
633	,, 35488	6	18 53 48·16	2·320	—0·004	3	70·538	60 0 8·60	4·674	0·341	3	70·538
634	,, 35473	7½	18 54 16·64	3·176	0·001	4	71·813	94 37 10·77	4·704	0·450	5	71·349
635	,, 35511	5	18 54 27·72	2·436	+0·001	4	70·303	63 56 50·78	4·720	0·344	5	70·351
636	,, 35561	7	18 55 44·02	2·564	0·000	5	70·573	68 40 7·78	4·828	0·360	5	70·573
637	,, 35584	5	18 56 0·32	2·435	0·002	4	70·008	63 53 30·22	4·851	0·343	3	70·160
638	,, 35598	6	18 56 57·61	3·034	0·001	5	72·019	88 22 1·35	4·933	0·427	5	72·019
639	,, 35799	7	19 1 19·42	2·917	—0·001	6	72·299	83 13 1·69	5·302	0·408	6	72·299
640	,, 35821	7½	19 1 21·17	2·551	+0·001	5	74·610	68 1 29·76	5·304	0·357	5	74·610

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641	LL 35810	7	19 1 37·54	+3·046	—0·001	5	71·162	88 54 11·93	—5·328	—0·427	5	71·162
642	„ 35857	7½	19 2 11·71	2·611	+0·001	5	70·990	70 20 21·73	5·374	0·361	5	70·990
643	„ 35926	6½	19 2 47·71	2·197	0·001	3	69·575	55 48 37·63	5·343	0·187	5	69·745
644	„ 35957	6½	19 3 49·00	2·326	0·002	5	70·503	59 54 18·78	5·513	0·326	5	70·510
645	„ 35996	6	19 4 18·30	2·192	0·001	4	70·327	55 36 49·01	5·552	0·306	4	70·327
646	„ 35968	7	19 4 40·62	2·959	—0·001	5	73·227	85 1 53·62	5·583	0·413	4	73·129
647	„ 36045	6½	19 5 15·62	2·157	+0·001	5	72·606	54 32 58·23	5·634	0·300	5	72·606
648	Anonyma	6½	19 6 7·48	2·440	0·002	6	71·222	63 49 0·96	5·706	0·339	6	71·222
649	LL 36130	7½	19 6 45·71	1·935	0·000	4	69·821	48 26 18·97	5·746	0·248	4	69·821
650	„ 36099	6½	19 7 19·86	2·952	—0·001	5	70·951	84 42 11·02	5·807	0·410	5	70·951
651	„ 36179	6	19 8 33·30	2·461	+0·001	6	72·468	64 27 45·17	5·908	0·341	6	72·468
652	„ 36224	7	19 8 35·34	1·693	—0·001	4	70·602	42 50 38·32	5·911	0·233	5	70·796
653	„ 36207	5½	19 9 24·65	2·732	+0·001	4	70·825	75 8 25·84	5·980	0·377	5	70·769
654	„ 36353	5	19 12 13·49	2·536	0·001	3	72·622	67 12 24·80	6·216	0·351	4	72·103
655	„ 36409	6½	19 12 53·51	2·047	0·001	5	71·798	51 6 39·97	6·270	0·280	4	72·108
656	„ 36461	6½	19 14 11·79	2·243	0·002	5	73·227	56 50 51·45	6·380	0·307	5	73·227
657	„ 36428	7½	19 14 18·04	2·859	—0·000	4	71·885	80 29 58·82	6·387	0·393	6	71·263
658	„ 36478	6½	19 14 26·48	2·109	+0·002	5	69·765	52 47 35·59	6·400	0·294	4	69·817
659	„ 36474	6½	19 15 28·11	2·284	0·001	5	71·188	58 8 32·88	6·485	0·314	5	71·188
660	„ 36489	5½	19 15 40·29	3·082	—0·002	4	71·596	90 29 46·16	6·501	0·424	4	71·598
661	„ 36540	6½	19 16 6·23	2·473	+0·002	6	71·767	64 38 24·12	6·536	0·337	5	73·197
662	„ 36597	6	19 18 7·46	3·184	—0·002	4	73·123	95 8 12·14	6·704	0·437	5	72·608
663	„ 36663	6	19 18 39·67	2·255	+0·002	6	70·070	57 2 4·64	6·748	0·307	7	69·988
664	„ 36683	6	19 19 9·26	2·407	0·001	5	71·623	62 9 53·23	6·789	0·327	5	71·623
665	„ 36785	6	19 21 16·54	2·431	0·001	5	72·441	62 56 23·32	6·963	0·330	5	72·441
666	„ 36789	6	19 21 40·19	2·663	0·000	5	73·391	71 57 53·25	6·996	0·363	5	73·391
667	„ 36821	6	19 22 18·02	2·674	0·000	3	69·894	72 24 54·06	7·027	0·336	5	69·944
668	„ 36791	6	19 22 21·47	3·231	—0·004	5	72·837	97 18 32·54	7·053	0·440	5	72·837
669	„ 36813	6½	19 22 38·56	3·071	0·003	5	70·595	90 1 6·60	7·076	0·417	5	70·595
670	„ 36890	6½	19 24 2·78	3·002	0·002	5	71·839	86 49 29·36	7·190	0·407	5	71·842
671	„ 36937	7	19 25 18·81	2·951	—0·001	5	72·650	84 30 14·58	7·292	0·400	5	72·650
672	„ 36978	6	19 25 24·78	2·248	+0·002	4	70·319	56 32 28·58	7·302	0·304	5	70·364
673	„ 36963	6½	19 25 59·04	2·872	—0·001	5	74·611	80 56 23·82	7·347	0·387	5	74·611
674	„ 36995	5½	19 26 2·13	2·455	+0·002	3	72·616	63 39 25·77	7·352	0·328	4	73·377
675	„ 36992	7½	19 26 50·07	3·180	—0·004	3	70·910	95 1 11·33	7·419	0·431	4	70·555
676	„ 37019	6½	19 27 21·36	2·958	0·001	4	69·565	84 48 42·46	7·459	0·397	4	69·565
677	„ 37064	6½	19 27 50·06	2·581	+0·001	5	72·643	68 25 52·43	7·498	0·346	5	72·643
678	„ 37077	6	19 27 51·79	2·327	0·002	5	70·632	59 2 32·10	7·501	0·311	5	70·605
679	„ 37057	6	19 28 28·63	3·239	—0·004	5	71·605	97 44 29·05	7·551	0·436	5	71·605
680	„ 37140	7	19 29 29·16	2·732	+0·000	5	70·997	74 40 25·94	7·634	0·364	5	71·605

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681	LL 37158	7	19 29 29·45	+2·389	+0·001	4	74·102	61 7 49·67	—7·633	—0·318	4	74·102
682	,, 37206	6½	19 30 1·35	1·973	0·001	5	72·225	48 21 20·63	7·676	0·263	5	72·225
683	,, 37216	7	19 30 32·11	2·226	0·001	3	69·912	55 35 51·54	7·717	0·297	3	69·912
684	,, 37207	7	19 31 34·76	3·298	—0·006	4	70·897	100 26 51·82	7·812	0·457	5	70·897
685	,, 37325	6	19 32 44·20	2·100	+0·001	5	73·443	51 41 50·99	7·893	0·276	5	73·443
686	,, 37323	6	19 32 51·99	2·219	0·002	5	71·246	55 16 9·56	7·904	0·295	5	71·246
687	,, 37292	6	19 33 26·08	3·194	—0·004	5	70·748	95 44 39·74	7·951	0·427	5	70·748
688	,, 37387	6	19 34 47·36	2·621	+0·000	5	70·431	69 49 18·67	8·059	0·347	5	70·431
689	,, 37410	6	19 34 51·32	2·255	0·002	5	71·237	56 19 10·15	8·065	0·297	5	71·237
690	,, 37487	6½	19 36 28·36	1·942	0·000	5	72·240	47 13 26·14	8·194	0·256	5	72·243
691	,, 37472	6½	19 36 34·10	2·447	0·002	4	69·808	62 55 16·49	8·202	0·323	5	69·745
692	,, 37495	6	19 37 13·11	2·452	0·001	5	70·375	63 3 8·13	8·253	0·321	5	70·375
693	,, 37513	6½	19 37 38·27	2·521	0·002	5	72·039	65 41 58·06	8·279	0·321	5	72·039
694	,, 37504	7½	19 38 5·12	2·972	—0·002	5	71·032	85 19 50·23	8·323	0·393	5	71·032
695	,, 37655	6	19 41 11·84	2·512	+0·002	5	70·759	65 10 59·49	8·570	0·330	5	70·759
696	,, 37676	7½	19 41 40·68	2·597	0·001	5	73·996	68 32 51·10	8·607	0·340	5	73·996
697	,, 37710	5	19 42 21·81	2·507	0·002	4	72·404	64 56 9·27	8·661	0·329	4	72·404
698	,, 37753	6	19 42 50·80	2·127	0·001	5	71·666	51 54 46·17	8·701	0·280	5	71·666
699	,, 37866	6½	19 46 6·51	2·153	0·002	7	72·098	52 30 13·47	8·956	0·277	7	72·098
700	,, 37847	5½	19 46 9·43	2·057	0·001	5	70·595	49 43 46·62	8·961	0·266	5	70·595
701	,, 37832	5½	19 46 29·97	3·143	−0·006	5	70·984	93 26 56·49	8·992	0·411	5	70·984
702	,, 37868	5	19 46 33·44	2·522	+0·001	5	75·030	65 20 23·06	8·992	0·326	5	75·030
703	,, 37957	6	19 48 3·93	1·807	−0·001	4	72·906	43 18 24·63	9·108	0·231	4	72·906
704	,, 37994	6	19 50 26·70	3·217	0·006	5	73·029	97 2 16·62	9·295	0·414	5	73·029
705	,, 38063	6½	19 51 5·41	2·556	+0·001	5	72·857	66 27 23·98	9·343	0·324	5	72·857
706	,, 38088	6½	19 51 33·11	2·372	0·002	5	75·011	59 23 59·53	9·380	0·303	5	75·011
707	,, 38084	7½	19 52 3·15	2·855	−0·002	5	70·438	79 37 14·31	9·420	0·369	5	70·438
708	,, 38047	7	19 52 8·42	3·044	0·003	5	70·153	88 40 54·30	9·426	0·497	5	70·153
709	,, 38100	6½	19 52 43·17	3·285	0·006	3	71·665	100 17 44·81	9·466	0·410	3	71·665
710	,, 38130	6½	19 53 2·35	2·843	0·001	5	71·015	79 2 44·54	9·495	0·363	5	71·018
711	,, 38177	5½	19 53 28·55	2·374	+0·002	4	73·362	59 22 3·76	9·528	0·301	4	73·362
712	,, 38233	6	19 54 49·59	2·503	0·001	5	72·276	64 10 1·23	9·632	0·317	5	72·276
713	,, 38237	7	19 55 7·10	2·653	0·001	5	74·806	70 21 7·75	9·654	0·336	5	74·806
714	,, 38214	6	19 55 17·06	3·181	−0·005	5	70·367	95 20 52·34	9·667	0·403	5	70·367
715	,, 38267	6	19 55 49·95	2·372	+0·001	6	71·646	59 7 37·02	9·709	0·300	6	71·646
716	,, 38281	7	19 56 44·87	2·982	−0·003	5	71·020	85 37 54·23	9·779	0·377	5	71·023
717	,, 38380	5½	19 58 16·66	2·411	+0·002	6	71·118	60 26 56·07	9·898	0·313	6	71·118
718	,, 38392	7	19 58 30·05	2·411	0·003	5	74·648	60 22 32·24	9·913	0·303	5	74·648
719	,, 38374	7	19 58 41·51	3·070	−0·004	7	72·100	89 54 46·87	9·926	0·390	7	72·100
720	,, 38459	6	20 1 9·97	3·215	0·006	5	72·278	97 8 7·37	10·105	0·403	5	72·278

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721	LL 38506	6	20 1 34·52	+2·888	−0·002	5	75·019	80 58 34·02	−10·144	−0·359	5	75·019
722	„ 38554	6	20 2 26·26	2·861	0·002	6	70·623	79 39 3·90	10·210	0·356	5	70·646
723	„ 38670	7½	20 4 31·04	2·319	+0·002	6	71·991	56 41 58·29	10·365	0·284	6	71·991
724	„ 38672	7½	20 4 41·43	2·470	0·007	5	74·032	62 6 45·38	10·380	0·303	5	74·032
725	„ 38694	7	20 5 24·76	2·678	0·000	5	75·459	71 1 7·34	10·433	0·329	5	75·459
726	„ 38706	6½	20 5 40·03	2·621	0·001	4	69·606	68 39 34·06	10·453	0·323	4	69·606
727	„ 38761	6	20 7 28·60	3·199	−0·006	5	71·223	96 26 20·73	10·588	0·396	5	71·223
728	„ 38821	6½	20 8 5·67	2·570	+0·001	5	74·626	66 9 13·63	10·632	0·313	5	74·626
729	„ 38830	6½	20 8 38·57	2·870	−0·002	5	71·874	79 55 17·55	10·673	0·350	5	71·874
730	„ 38896	5	20 9 45·38	2·539	0·001	4	70·656	64 48 12·76	10·763	0·313	4	70·656
731	„ 38944	7½	20 10 16·30	2·213	+0·003	3	71·002	52 42 3·60	10·793	0·267	3	71·002
732	„ 38942	7½	20 11 18·21	3·172	−0·006	5	73·637	95 7 45·62	10·870	0·384	5	73·637
733	„ 38995	7	20 12 26·10	3·035	0·004	5	73·459	88 10 14·71	10·953	0·367	5	73·459
734	„ 39023	7½	20 13 4·39	3·040	0·003	5	70·847	88 24 44·01	11·000	0·366	4	70·884
735	„ 39102	6½	20 14 27·22	2·722	+0·001	5	75·037	72 36 52·01	11·100	0·326	5	75·037
736	„ 39149	7	20 14 39·48	1·922	0·000	3	69·613	44 5 3·12	11·116	0·230	3	69·613
737	„ 39108	7½	20 15 0·44	3·046	−0·005	5	71·854	88 44 23·75	11·142	0·367	5	71·854
738	„ 39127	7½	20 15 0·57	2·625	+0·001	5	71·868	68 7 57·78	11·140	0·313	5	71·868
739	„ 39181	7	20 16 13·47	2·427	0·001	5	70·661	59 49 24·20	11·229	0·288	5	70·661
740	„ 39251	6	20 17 26·77	2·121	0·002	5	71·665	49 16 56·12	11·317	0·251	6	71·836
741	„ 39294	7	20 18 47·11	2·472	0·002	5	74·271	61 25 5·41	11·414	0·291	5	74·271
742	„ 39313	5½	20 18 52·44	2·241	0·002	5	70·050	52 56 31·50	11·421	0·264	6	70·142
743	„ 39304	7	20 19 28·91	2·886	−0·000	5	72·118	80 21 53·08	11·464	0·341	5	72·118
744	„ 39337	7	20 20 52·12	3·187	0·007	5	71·417	96 4 50·75	11·564	0·377	5	71·417
745	„ 39426	6	20 22 3·04	2·340	+0·002	3	69·682	56 5 52·01	11·647	0·271	3	69·682
746	„ 39432	7½	20 22 28·85	2·638	0·000	5	73·887	68 17 29·83	11·680	0·308	5	73·887
747	„ 39464	7½	20 22 45·01	2·068	0·002	5	71·285	47 16 50·25	11·697	0·240	5	71·285
748	„ 39496	7	20 23 39·50	2·197	0·002	5	72·028	51 6 8·42	11·762	0·254	5	72·028
749	„ 39506	7½	20 24 23·27	2·699	0·001	4	69·887	71 9 45·04	11·815	0·314	4	69·887
750	„ 39591	7	20 25 41·63	1·977	0·001	5	71·895	44 30 43·09	11·907	0·233	5	71·895
751	„ 39540	6½	20 25 43·02	3·038	−0·003	4	74·408	88 13 5·94	11·908	0·353	5	74·665
752	„ 39595	5½	20 26 24·41	2·562	+0·002	4	69·888	64 37 58·75	11·957	0·296	4	69·888
753	„ 39599	7½	20 26 30·71	2·573	0·001	5	71·643	65 5 14·15	11·963	0·296	5	71·643
754	„ 39644	7	20 27 21·66	2·531	0·002	5	73·075	63 13 44·31	12·023	0·290	5	73·075
755	„ 39692	7½	20 28 18·86	2·392	0·002	5	70·861	57 32 5·96	12·090	0·273	5	70·861
756	„ 39724	7	20 28 56·40	2·347	0·003	5	70·625	55 45 54·98	12·133	0·267	5	70·625
757	„ 39699	7½	20 29 6·19	2·950	−0·003	5	73·887	83 29 59·67	12·145	0·338	5	73·887
758	„ 39690	7	20 29 6·69	3·079	0·004	5	72·306	90 26 50·36	12·147	0·367	5	72·306
759	„ 39760	7	20 30 38·33	3·077	0·005	5	70·456	90 21 12·06	12·252	0·353	5	70·456
760	„ 39788	6½	20 31 18·07	3·160	0·007	4	72·670	94 50 2·58	12·297	0·361	4	72·670

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761	LL 39885	6	20 32 30·09	+2·253	+0·003	6	71·009	52 7 21·77	—12·381	—0·254	6	71·009
762	„ 39855	7	20 32 35·80	2·831	—0·002	5	69·637	77 8 23·00	12·394	0·309	5	69·637
763	„ 39905	6	20 33 24·06	2·661	+0·001	5	71·285	68 38 21·75	12·442	0·300	5	71·285
764	„ 39923	7	20 33 46·30	2·569	0·001	4	73·700	64 23 8·14	12·468	0·288	5	73·722
765	„ 39967	7	20 34 50·03	2·342	0·003	5	73·896	55 4 10·68	12·538	0·258	5	73·896
766	„ 40103	7½	20 38 58·62	2·239	0·004	5	73·470	51 0 31·07	12·836	0·267	5	73·470
767	„ 40097	7	20 39 33·59	2·947	—0·002	5	70·856	83 5 36·32	12·861	0·327	5	70·856
768	„ 40172	7½	20 41 30·12	2·436	+0·003	4	69·660	58 3 17·10	12·990	0·266	4	69·660
769	„ 40193	6½	20 42 20·09	2·551	0·003	4	69·713	62 52 54·30	13·046	0·280	4	69·713
770	„ 40182	7	20 42 36·06	3·089	—0·005	5	71·299	91 2 31·61	13·063	0·337	5	71·299
771	„ 40212	7½	20 42 47·19	2·650	+0·002	5	72·955	67 28 1·61	13·075	0·288	5	72·955
772	„ 40249	6½	20 43 5·71	2·256	0·004	5	73·199	51 11 26·81	13·095	0·243	5	73·199
773	„ 40316	7½	20 45 35·59	2·925	—0·002	5	71·093	81 42 48·50	13·260	0·316	5	71·093
774	„ 40334	6½	20 45 44·65	2·388	+0·003	5	70·063	55 43 52·72	13·271	0·256	5	70·063
775	„ 40369	7½	20 46 32·80	2·265	0·004	5	74·685	51 5 38·47	13·323	0·241	5	74·685
776	„ 40367	6	20 46 42·78	2·438	0·003	5	70·303	57 38 17·65	13·334	0·266	5	70·303
777	„ 40373	7	20 46 51·82	2·394	0·004	5	72·960	55 49 47·56	13·344	0·261	5	72·960
778	„ 40356	7	20 47 14·24	3·159	—0·006	5	71·486	95 2 0·37	13·370	0·330	5	71·486
779	„ 40405	7	20 48 25·00	3·103	0·005	3	73·028	91 52 1·11	13·445	0·333	3	73·028
780	„ 40450	6½	20 49 29·84	3·141	0·006	3	70·672	94 3 28·51	13·515	0·340	3	70·672
781	„ 40515	7½	20 50 22·10	2·543	+0·003	5	72·933	61 47 45·41	13·571	0·269	5	72·933
782	„ 40518	6½	20 50 27·84	2·568	0·003	3	70·070	62 55 17·16	13·578	0·271	3	70·070
783	„ 40590	7	20 51 21·68	2·130	0·003	5	73·512	46 7 27·23	13·659	0·221	5	73·512
784	„ 40626	6	20 52 48·07	2·511	0·003	5	73·121	60 6 23·83	13·727	0·261	5	73·121
785	„ 40649	7	20 53 39·87	2·951	—0·004	5	73·509	82 59 21·35	13·783	0·314	5	73·509
786	„ 40706	6	20 54 15·43	2·150	+0·003	4	71·721	46 26 39·25	13·829	0·234	4	71·721
787	„ 40720	7	20 54 20·06	1·919	0·002	5	70·079	40 2 31·76	13·830	0·200	5	70·079
788	„ 40705	7	20 54 37·54	2·467	0·004	5	74·829	58 0 33·87	13·843	0·254	5	74·829
789	„ 40735	7½	20 54 54·77	2·147	0·003	4	71·974	46 16 44·06	13·863	0·123	4	71·974
790	„ 40764	6½	20 56 2·49	2·385	0·004	5	71·289	54 28 56·59	13·933	0·246	5	71·289
791	„ 40739	7	20 56 9·51	3·023	—0·004	4	70·147	87 9 34·45	13·938	0·311	4	70·147
792	„ 40755	7	20 56 25·50	2·882	0·000	5	73·488	78 51 14·36	13·957	0·298	5	73·488
793	„ 40788	6½	20 57 2·30	2·604	+0·003	5	74·091	64 0 12·08	13·995	0·267	5	74·091
794	„ 40805	6½	20 57 6·24	2·157	0·004	6	71·210	46 19 15·02	14·062	0·309	6	71·210
795	„ 40806	6	20 58 9·28	3·042	—0·003	6	73·374	88 14 34·51	14·064	0·311	5	73·478
796	„ 40826	6½	20 58 42·62	3·152	0·007	5	70·072	94 52 42·04	14·102	0·326	5	70·072
797	„ 40873	7	20 59 40·92	2·821	0·001	4	70·685	75 11 15·90	14·159	0·286	4	70·685
798	„ 40884	7	21 0 40·11	3·092	0·005	4	71·449	91 17 11·62	14·189	0·313	4	71·449
799	„ 40977	6	21 2 14·86	3·050	0·004	5	70·870	88 44 11·19	14·318	0·297	5	70·870
800	„ 41030	7	21 3 0·99	2·342	+0·004	5	72·727	51 59 44·24	14·364	0·233	5	72·727

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801	LL 41064	7½	21 3 29·64	+2·196	+0·004	5	71·699	46 46 44·32	—14·392	—0·202	5	71·699
802	„ 41143	7	21 5 18·43	2·149	0·004	4	70·161	45 1 33·92	14·512	0·221	5	70·057
803	„ 41155	7	21 5 50·06	2·408	0·005	6	71·906	54 13 51·12	14·536	0·237	6	71·906
804	„ 41269	6½	21 8 36·85	2·560	0·005	4	69·908	60 38 8·14	14·703	0·249	5	69·908
805	„ 41259	7	21 8 40·28	2·811	0·001	5	71·339	74 3 29·16	14·706	0·274	5	71·339
806	„ 41299	7	21 9 37·45	2·808	0·000	5	75·267	73 48 32·45	14·764	0·274	5	75·267
807	„ 41347	7½	21 9 52·43	1·907	0·003	4	71·986	37 49 31·85	14·778	0·184	4	71·986
808	„ 41312	7	21 9 53·28	2·757	0·001	4	73·486	70 49 32·36	14·778	0·267	5	73·365
809	„ 41293	6½	21 9 56·01	3·105	−0·006	5	71·936	92 8 53·38	14·781	0·303	5	71·936
810	„ 41326	7	21 10 12·50	2·652	+0·003	5	70·912	65 6 18·45	14·787	0·257	5	70·912
811	„ 41380	7½	21 11 4·54	2·093	0·005	4	73·180	42 34 0·02	14·848	0·200	4	73·180
812	„ 41376	7½	21 11 23·71	2·425	0·005	4	70·502	54 13 11·79	14·866	0·216	4	70·502
813	„ 41420	6½	21 12 51·76	2·672	0·003	5	71·282	65 53 9·86	14·953	0·256	5	71·282
814	„ 41448	7½	21 13 50·02	2·876	0·000	4	71·709	77 35 9·48	15·010	0·274	5	71·319
815	„ 41476	6	21 14 19·60	2·723	0·003	4	71·223	68 31 23·60	15·037	0·257	4	71·223
816	„ 41588	6	21 17 6·45	2·572	0·005	4	70·177	60 14 42·26	15·199	0·241	4	70·177
817	„ 41610	7	21 17 32·29	2·587	0·004	5	71·923	60 54 37·66	15·218	0·234	5	71·926
818	„ 41624	6½	21 17 35·60	2·389	0·006	5	71·154	51 55 11·09	15·226	0·221	5	71·154
819	„ 41619	7½	21 17 41·76	2·584	0·004	5	74·447	60 44 33·30	15·231	0·238	5	74·447
820	„ 41627	7	21 17 43·23	2·388	0·005	4	72·803	51 50 50·15	15·233	0·221	5	72·819
821	„ 41674	6	21 19 1·33	2·662	0·003	4	69·989	64 40 41·25	15·305	0·283	4	69·989
822	„ 41710	7	21 20 24·00	2·778	0·000	5	70·299	71 11 9·34	15·382	0·261	5	70·299
823	„ 41723	8½	21 20 47·52	2·998	—0·003	5	73·341	85 10 11·68	15·406	0·326	5	73·341
824	„ 41734	7	21 20 58·83	2·833	+0·001	5	71·536	74 26 6·51	15·418	0·260	5	71·536
825	„ 41761	7½	21 21 47·76	2·631	0·004	5	74·085	62 41 24·12	15·462	0·238	5	74·085
826	„ 41814	6½	21 22 54·43	2·669	0·001	5	70·351	64 38 40·11	15·525	0·203	5	70·351
827	„ 41913	7½	21 25 31·37	2·433	0·006	4	72·977	52 36 15·56	15·669	0·218	4	72·977
828	„ 41957	7	21 26 57·97	2·767	0·002	5	70·354	69 51 38·74	15·748	0·247	5	70·354
829	„ 41981	7½	21 27 18·32	2·551	0·005	5	75·283	57 47 50·66	15·764	0·224	5	75·283
830	„ 41978	7	21 27 22·17	2·754	0·002	5	72·942	68 59 6·09	15·768	0·243	5	72·942
831	„ 42031	7½	21 28 40·10	2·809	0·002	5	72·709	72 14 56·96	15·838	0·247	5	72·709
832	„ 42052	6½	21 29 12·21	2·760	0·003	3	69·645	69 10 26·20	15·865	0·223	3	69·645
833	„ 42054	7	21 29 43·50	3·151	−0·007	5	72·364	95 37 58·24	15·898	0·280	4	72·525
834	„ 42095	7½	21 30 23·33	2·852	+0·001	5	70·781	74 53 15·46	15·932	0·251	5	70·781
835	BAC 7515	6½	21 30 53·09	3·086	—0·007	5	74·095	90 58 19·26	15·955	0·274	5	74·095
836	„ 7522	5	21 32 1·20	2·997	0·004	4	71·218	84 48 48·99	16·015	0·265	4	71·218
837	LL 42200	6	21 32 53·71	2·699	+0·005	5	71·776	65 5 12·47	16·062	0·230	5	71·776
838	„ 42199	5½	21 32 57·51	2·784	0·001	4	70·465	70 19 12·44	16·066	0·244	5	70·529
839	„ 42241	7½	21 33 22·93	2·335	0·008	5	72·149	47 17 41·73	16·089	0·197	5	72·149
840	„ 42213	7½	21 33 37·78	2·951	—0·000	3	69·671	81 24 8·92	16·096	0·246	4	69·675

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841	LL 42273	7	21 34 56·83	+2·648	+0·005	5	72·534	61 50 4·65	−16·169	−0·224	5	72·534
842	,, 42310	6½	21 35 37·92	2·769	0·004	4	71·269	68 59 14·45	16·205	0·233	4	71·269
843	,, 42295	6	21 35 45·12	3·001	−0·002	4	74·941	84 54 40·13	16·211	0·256	5	75·124
844	,, 42396	7½	21 37 33·31	2·091	+0·016	5	71·306	38 18 3·23	16·302	0·244	5	71·306
845	,, 42384	6	21 38 13·15	3·038	−0·004	5	74·283	87 36 12·68	16·336	0·232	5	74·283
846	,, 42431	6½	21 39 47·87	3·109	0·006	5	71·353	92 48 44·12	16·416	0·254	5	71·353
847	,, 42470	6½	21 40 13·76	2·530	+0·007	5	70·752	54 44 29·30	16·438	0·206	5	70·752
848	,, 42476	6½	21 40 37·68	2·810	0·003	5	72·754	71 7 21·30	16·458	0·228	5	72·754
849	,, 42524	7½	21 42 14·69	2·737	0·005	4	70·768	66 8 14·81	16·539	0·221	4	70·768
850	,, 42542	7½	21 42 46·70	2·769	0·003	5	73·933	68 10 26·89	16·565	0·222	5	73·933
851	,, 42549	7½	21 43 8·20	2·867	0·002	5	70·532	74 50 34·48	16·583	0·231	5	70·532
852	,, 42594	7	21 44 17·62	2·723	0·005	5	72·131	65 0 34·78	16·639	0·216	5	72·131
853	,, 42619	6½	21 45 29·55	2·934	0·000	5	71·203	79 31 3·89	16·697	0·232	5	71·203
854	,, 42654	6	21 46 14·42	2·793	0·003	5	72·139	69 20 13·53	16·734	0·217	5	72·139
855	,, 42713	6½	21 48 5·95	2·688	0·006	5	73·712	62 15 58·77	16·823	0·207	5	73·712
856	,, 42708	7	21 48 10·78	2·819	0·003	5	71·167	70 53 37·74	16·826	0·217	5	71·167
857	,, 42748	7½	21 49 12·35	2·625	0·007	4	74·202	58 16 31·76	16·874	0·200	4	74·202
858	,, 42756	6½	21 49 21·83	2·581	0·008	4	71·034	55 50 27·17	16·884	0·200	4	71·034
859	,, 42797	7½	21 50 31·95	2·610	0·006	4	71·759	57 14 57·43	16·937	0·197	5	72·545
860	,, 42849	7½	21 51 39·58	2·682	0·006	6	70·191	61 18 23·49	16·990	0·201	5	70·086
861	,, 42846	6	21 52 8·16	3·132	−0·007	5	71·557	94 59 2·28	17·012	0·237	4	71·733
862	,, 42878	7½	21 52 38·46	2·514	+0·008	5	72·546	51 41 31·92	17·034	0·186	5	72·546
863	,, 42875	7½	21 53 8·20	2·948	−0·001	3	71·405	80 2 41·40	17·058	0·221	5	71·338
864	,, 42943	6½	21 54 43·83	2·630	+0·008	4	70·797	57 37 9·68	17·131	0·193	4	70·797
865	,, 42974	6½	21 55 37·98	2·519	0·009	5	74·477	51 22 42·61	17·174	0·181	5	74·477
866	,, 42963	7½	21 56 7·71	3·181	−0·008	5	69·668	99 7 34·82	17·194	0·233	5	69·668
867	,, 42989	7	21 56 23·29	2·882	+0·002	5	72·381	74 38 21·57	17·205	0·208	5	72·381
868	,, 42994	7½	21 56 28·25	2·780	0·005	5	74·120	67 2 49·64	17·209	0·200	5	74·120
869	,, 43018	6	21 57 1·18	2·674	0·007	5	71·918	59 51 17·37	17·234	0·193	5	71·918
870	,, 43081	5	21 59 13·75	2·742	0·006	5	73·308	63 57 27·95	17·331	0·194	5	73·308
871	,, 43104	6½	22 0 22·59	3·201	−0·011	3	72·412	101 4 48·38	17·387	0·235	3	72·412
872	,, 43142	7	22 1 5·50	2·966	0·000	4	71·019	80 57 45·45	17·422	0·210	5	70·966
873	,, 43160	7½	22 1 16·07	2·694	+0·008	5	74·301	60 18 56·45	17·422	0·188	5	74·301
874	,, 43151	6	22 1 16·91	2·864	0·003	5	72·950	72 37 56·01	17·422	0·201	5	72·950
875	,, 43196	5½	22 2 17·20	2·764	0·002	4	71·462	65 5 25·26	17·426	0·136	4	71·462
876	,, 43250	6½	22 3 25·94	2·413	−0·004	4	70·177	44 53 43·06	17·472	0·104	4	70·177
877	,, 43256	7½	22 3 32·52	2·366	+0·012	5	74·522	42 42 7·48	17·519	0·161	5	74·522
878	,, 43266	6½	22 3 56·56	2·440	0·012	5	74·688	45 47 25·45	17·536	0·165	5	74·688
879	,, 43255	6½	22 4 7·37	2·848	0·005	3	70·739	71 1 5·56	17·543	0·196	4	70·742
880	,, 43258	6½	22 4 14·63	2·945	0·001	5	72·732	79 0 43·73	17·548	0·200	5	72·732

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881	LL 43309	7	22 5 41·25	+3·048	+0·002	4	72·227	87 54 21·13	−17·610	−0·209	5	71·756
882	„ 43331	6½	22 6 5·60	2·783	0·006	4	71·438	65 41 24·39	17·627	0·188	5	71·106
883	„ 43383	7	22 7 16·00	2·662	0·010	5	72·554	57 2 28·41	17·675	0·177	5	72·554
884	„ 43386	7½	22 7 58·49	3·143	−0·007	4	75·011	96 31 37·84	17·704	0·208	4	75·011
885	„ 43392	6½	22 8 0·10	2·990	0·000	5	70·930	82 40 3·13	17·705	0·199	6	70·900
886	„ 43443	6½	22 9 31·28	2·985	0·000	3	70·402	82 5 46·47	17·767	0·196	5	70·172
887	„ 43493	5	22 10 18·21	2·605	+0·010	4	74·241	52 53 52·54	17·800	0·170	4	74·241
888	„ 43524	7	22 11 22·86	2·777	0·007	5	75·095	64 15 44·16	17·842	0·178	5	75·095
889	„ 43518	7	22 11 24·31	3·080	−0·004	3	71·389	90 53 4·48	17·850	0·196	4	71·230
890	„ 43533	6½	22 11 46·30	2·869	+0·004	5	72·971	71 36 30·54	17·858	0·193	5	72·971
891	„ 43537	7½	22 12 12·08	2·994	0·000	4	70·733	82 47 3·28	17·875	0·191	5	70·561
892	„ 43568	7½	22 13 7·17	2·764	0·008	5	73·911	62 58 6·33	17·911	0·174	5	73·911
893	„ 43584	7½	22 13 30·94	2·669	0·009	5	71·159	56 6 40·00	17·927	0·167	5	71·159
894	„ 43630	7	22 14 45·05	2·630	0·012	5	74·298	53 21 15·46	17·976	0·164	5	74·298
895	„ 43635	7½	22 15 6·99	2·721	0·008	4	72·770	59 20 35·08	17·990	0·168	4	72·770
896	„ 43648	7½	22 15 45·81	2·914	0·004	4	70·776	75 0 9·62	18·020	0·189	5	70·771
897	„ 43650	7½	22 16 2·57	3·011	−0·001	5	72·116	84 10 53·85	18·026	0·190	5	72·116
898	„ 43706	7½	22 16 58·16	2·695	+0·011	4	72·935	57 3 33·69	18·060	0·164	4	72·935
899	„ 43734	8	22 18 6·03	2·911	0·004	5	72·276	74 23 39·53	18·103	0·176	4	72·276
900	„ 43751	6½	22 18 9·11	2·623	0·012	5	74·482	52 5 17·01	18·103	0·157	4	74·675
901	„ 43782	7	22 18 58·90	2·793	0·008	5	73·357	64 2 50·82	18·137	0·168	5	73·357
902	„ 43859	6½	22 20 59·33	2·653	0·012	5	71·537	53 13 1·81	18·210	0·154	5	71·537
903	„ 43886	6½	22 21 44·62	2·619	0·012	5	73·340	50 51 6·85	18·237	0·151	5	73·340
904	„ 43891	7	22 22 6·00	2·823	0·007	5	72·951	65 52 14·50	18·248	0·160	5	72·951
905	„ 43893	6	22 22 6·94	2·797	0·008	4	71·008	63 38 34·47	18·251	0·161	4	71·008
906	„ 43974	6½	22 24 29·06	3·140	−0·006	4	70·567	97 13 3·80	18·338	0·183	5	70·604
907	„ 44035	7	22 25 31·78	2·644	+0·013	5	71·548	51 25 16·76	18·374	0·149	5	71·548
908	„ 44019	7	22 25 44·10	3·138	−0·007	5	72·774	97 8 11·39	18·380	0·179	5	72·774
909	„ 44022	7	22 25 45·17	3·053	0·002	5	75·111	88 4 49·79	18·380	0·171	5	75·111
910	„ 44229	7	22 31 21·73	2·854	+0·008	5	72·787	66 40 20·98	18·572	0·151	5	72·787
911	„ 44252	6½	22 31 32·86	2·617	0·017	3	69·777	47 51 50·72	18·578	0·137	4	70·021
912	„ 44351	7	22 34 12·78	2·899	0·006	5	73·776	70 38 7·22	18·663	0·147	5	73·776
913	„ 44459	7½	22 37 13·57	3·045	0·000	5	74·715	86 48 20·99	18·758	0·150	5	74·715
914	„ 44492	6½	22 37 51·55	2·717	0·013	5	72·590	52 58 54·12	18·778	0·131	5	72·590
915	„ 44540	7	22 39 38·01	2·917	0·005	5	70·778	71 25 59·86	18·832	0·140	5	70·778
916	„ 44573	7½	22 40 32·44	2·858	0·011	4	73·033	64 52 50·06	18·859	0·134	4	73·033
917	„ 44639	7	22 41 54·06	2·484	0·021	5	72·208	37 18 10·54	18·900	0·114	5	72·208
918	„ 44625	7½	22 42 8·45	3·015	0·002	5	73·514	82 50 26·83	18·907	0·141	5	73·514
919	„ 44692	7½	22 44 29·31	2·936	0·006	4	73·545	72 41 9·73	18·974	0·131	4	73·545
920	„ 44721	6½	22 45 13·12	2·865	0·010	5	71·798	64 17 53·36	18·995	0·127	5	71·798

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921	LL 44726	7	22 45 16·31	+ 2·678	+0·017	5	74·549	47 27 0·92	− 18·996	− 0·118	4	74·512
922	„ 44845	6½	22 48 42·86	2·860	0·011	5	73·032	62 40 59·66	19·090	0·120	5	73·032
923	„ 44854	6½	22 48 59·98	2·771	0·015	5	74·184	53 36 57·37	19·098	0·117	5	74·184
924	„ 44862	6	22 49 41·11	2·781	0·017	4	71·092	54 20 30·42	19·116	0·116	4	71·092
925	„ 44888	6	22 50 55·51	3·049	− 0·001	6	71·804	86 53 8·17	19·149	0·126	5	72·212
926	„ 44939	7½	22 52 42·68	3·046	0·000	5	70·840	86 20 6·44	19·194	0·121	5	70·840
927	„ 44963	7	22 52 51·65	2·709	0·010	6	73·945	46 51 24·41	19·198	0·106	6	73·945
928	„ 44966	7	22 53 23·57	3·041	0·000	4	73·304	85 32 13·47	19·211	0·120	4	73·304
929	„ 45023	6½	22 54 30·37	2·850	+ 0·013	4	72·819	59 36 52·36	19·263	0·144	4	72·819
930	„ 45112	7½	22 57 14·66	2·920	0·010	5	72·601	67 19 17·35	19·306	0·110	5	72·601
931	„ 45166	6	22 58 43·70	2·915	0·010	3	73·174	66 10 45·80	19·340	0·106	4	72·844
932	„ 45203	6½	23 0 4·14	2·819	0·015	4	71·603	53 52 52·72	19·370	0·100	4	71·603
933	„ 45199	6	23 0 4·92	2·951	0·008	5	73·379	70 47 29·30	19·370	0·104	5	73·379
934	„ 45218	7½	23 0 24·74	2·763	0·020	5	74·440	48 6 33·89	19·378	0·095	5	74·440
935	„ 45241	5½	23 1 4·08	2·944	0·009	5	74·613	69 34 0·92	19·393	0·103	5	74·613
936	„ 45234	7	23 1 5·72	3·077	0·002	5	72·570	90 59 57·06	19·394	0·109	5	72·570
937	„ 45334	7½	23 3 28·76	2·991	0·005	3	74·493	76 16 28·92	19·447	0·101	3	74·493
938	„ 45333	7½	23 3 31·90	3·033	0·001	4	72·551	83 20 30·97	19·447	0·102	4	72·551
939	„ 45350	6½	23 3 55·23	2·860	0·014	5	73·396	56 56 8·47	19·455	0·094	5	73·396
940	„ 45362	6½	23 4 21·65	2·916	0·011	5	68·459	64 10 54·69	19·464	0·095	5	68·607
941	„ 45426	7½	23 6 13·18	2·843	0·017	4	72·844	53 44 19·18	19·503	0·090	4	72·844
942	„ 45469	7½	23 7 18·34	2·991	0·006	5	70·842	75 20 13·71	19·525	0·093	5	70·842
943	„ 45490	6	23 7 53·63	3·132	− 0·008	5	72·835	101 23 44·27	19·537	0·097	5	72·835
944	„ 45496	7½	23 8 2·80	2·904	+ 0·013	5	73·990	60 56 7·99	19·540	0·088	5	73·990
945	„ 45620	7	23 11 34·31	2·911	0·014	4	73·493	60 15 1·97	19·606	0·081	4	73·493
946	„ 45670	7½	23 12 57·25	2·822	0·021	4	71·541	47 34 41·75	19·630	0·074	3	71·778
947	„ 45677	6	23 13 10·13	2·887	0·016	4	71·887	55 55 4·48	19·635	0·079	4	71·887
948	„ 45672	7½	23 13 13·09	3·036	0·003	5	73·416	82 43 42·13	19·636	0·083	5	73·416
949	„ 45743	6	23 14 35·12	2·822	0·020	5	71·992	46 35 39·58	19·666	0·083	5	71·992
950	„ 45780	5½	23 16 3·69	2·951	0·012	5	75·679	64 47 37·65	19·685	0·074	5	75·679
951	„ 45821	7½	23 17 40·23	2·935	0·017	5	71·041	61 2 26·97	19·712	0·073	5	71·041
952	„ 45829	7½	23 17 51·80	2·979	0·010	5	72·430	69 17 56·30	19·715	0·073	5	72·430
953	„ 45843	7	23 18 24·72	2·898	0·019	5	72·963	54 21 6·12	19·723	0·068	5	72·963
954	„ 45858	7½	23 19 1·50	2·902	0·018	4	73·778	54 32 59·74	19·733	0·068	5	73·784
955	„ 45951	7½	23 21 27·44	2·930	0·017	3	71·599	57 45 19·69	19·770	0·066	3	71·599
956	„ 45965	6½	23 22 17·32	3·110	− 0·006	4	70·822	99 58 52·81	19·782	0·069	4	70·822
957	„ 45978	7½	23 22 29·22	2·877	+ 0·023	5	71·795	48 18 15·75	19·785	0·070	5	71·795
958	„ 45994	7½	23 23 0·45	2·880	0·023	4	72·541	48 21 22·49	19·792	0·061	5	72·009
959	„ 46047	6	23 24 18·99	2·909	0·020	5	72·773	52 3 17·58	19·810	0·059	5	72·773
960	„ 46082	7	23 25 8·95	2·940	0·017	4	70·584	57 1 4·51	19·822	0·058	4	70·584

No.	Star.	Mag.	AR for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.	N.P.D. for 1870.	Prec.	Sec. Var.	Obs.	Mean Epoch.
961	LL 46090	6½	23 25 41.73	+3.112	−0.007	4	73.117	101 43 0.41	−19.829	−0.063	5	73.258
962	„ 46117	7, 8	23 26 14.44	3.083	0.003	3	71.154	93 44 3.74	19.836	0.061	4	70.836
963	„ 46168	7½	23 27 32.74	2.876	+0.027	4	72.103	44 2 7.14	19.857	0.051	4	72.103
964	„ 46182	7½	23 28 8.51	2.948	0.018	4	73.800	56 21 46.56	19.858	0.051	4	73.800
965	„ 46195	6½	23 28 23.55	2.931	0.020	4	70.049	52 41 41.94	19.862	0.051	5	68.987
966	„ 46203	7½	23 28 30.11	2.903	0.025	4	75.647	47 30 59.40	19.863	0.050	4	75.647
967	„ 46227	7	23 29 4.17	2.961	0.017	4	70.869	58 31 15.45	19.870	0.051	5	70.672
968	„ 46229	7½	23 29 17.76	3.101	−0.005	4	73.570	99 29 2.61	19.872	0.053	5	73.620
969	„ 46320	7	23 32 7.27	2.960	+0.019	5	71.863	55 41 8.05	19.904	0.046	5	71.863
970	„ 46482	7	23 36 37.83	2.979	0.019	5	71.857	55 58 18.95	19.949	0.039	5	71.857
971	„ 46491	7½	23 36 52.64	2.896	0.026	4	74.792	38 28 25.79	19.951	0.046	4	73.064
972	„ 46518	7	23 37 52.04	3.080	−0.002	5	70.612	93 53 45.93	19.959	0.037	5	70.612
973	„ 46532	7½	23 38 20.22	3.074	+0.000	3	73.542	91 22 56.62	19.963	0.036	4	73.611
974	„ 46541	6½	23 38 29.92	3.024	0.013	5	71.252	69 19 51.86	19.964	0.034	4	71.623
975	„ 46616	7½	23 41 4.04	2.997	0.019	4	70.582	56 12 1.04	19.984	0.029	4	70.582
976	„ 46640	6½	23 41 58.20	3.022	0.015	5	70.014	65 4 5.23	19.991	0.030	5	70.014
977	„ 46642	7½	23 42 1.33	3.016	0.016	4	74.077	62 21 5.02	19.991	0.028	5	74.025
978	„ 46645	7½	23 42 3.86	2.996	0.021	4	71.681	54 26 50.63	19.992	0.029	5	71.118
979	„ 46688	7½	23 43 36.17	3.027	0.012	5	73.398	65 51 54.84	20.001	0.024	5	73.398
980	„ 46742	7	23 45 14.47	3.065	0.003	4	71.824	85 58 42.38	20.013	0.026	4	71.824
981	„ 46746	7	23 45 20.16	3.006	0.022	5	70.401	52 49 44.89	20.012	0.021	5	70.401
982	„ 46757	7	23 45 37.10	2.973	0.033	4	72.145	40 36 33.47	20.013	0.020	5	71.494
983	„ 46791	7½	23 46 18.96	2.983	0.033	3	70.866	42 14 30.48	20.017	0.020	3	70.866
984	„ 46803	7	23 46 30.58	3.034	0.014	4	74.626	64 43 24.33	20.018	0.020	5	74.464
985	„ 46808	7	23 46 35.89	3.024	0.018	4	73.540	58 48 47.08	20.019	0.020	4	73.540
986	„ 46867	6½	23 48 22.14	3.035	0.017	5	70.436	62 5 27.70	20.027	0.017	5	70.436
987	„ 46906	6	23 49 20.83	3.048	0.013	5	69.632	69 33 29.76	20.031	0.014	5	69.632
988	„ 46909	7½	23 49 28.45	3.035	0.019	5	72.475	59 38 37.33	20.030	0.011	5	72.475
989	„ 46911	7	23 49 31.32	3.032	0.020	5	73.779	57 14 9.06	20.032	0.014	5	73.779
990	„ 46981	6	23 51 43.89	3.038	0.022	5	73.201	55 42 39.56	20.038	0.007	5	73.201
991	„ 47002	7	23 52 10.01	3.041	0.020	4	71.821	56 58 35.58	20.041	0.008	4	71.821
992	„ 47034	5½	23 52 51.95	3.044	0.020	3	72.847	56 59 45.64	20.044	0.009	4	73.103
993	„ 47094	6½	23 55 3.63	3.057	0.019	5	70.215	66 28 10.91	20.047	0.007	5	70.215
994	„ 47142	7½	23 55 53.13	3.064	0.009	5	71.661	74 28 4.96	20.050	0.003	5	71.661
995	„ 47150	7½	23 56 6.64	3.055	0.022	3	73.756	54 54 31.27	20.050	0.001	3	73.756
996	„ 47148	7½	23 56 7.21	3.070	0.002	3	75.563	88 35 29.00	20.050	0.002	3	75.563
997	„ 47216	7	23 58 20.15	3.066	0.017	5	71.055	63 2 57.33	20.053	0.003	5	71.055
998	„ 47245	7	23 59 15.89	3.069	0.015	6	72.147	66 9 16.62	20.053	0.004	5	72.192
999	„ 47251	7	23 59 22.89	3.068	0.026	3	73.805	50 18 19.23	20.053	0.004	4	73.808
1000	„ 47264	7	23 59 54.63	3.071	0.016	3	75.510	62 10 11.59	20.053	0.006	3	75.510

PROPER MOTION.

All the stars in this Catalogue were brought back to 1825 to compare them with Weisse, and where there was a difference of not less than either 0·5ˢ in AR. or 5″ in PD., or thereabouts, a proper motion was assumed and calculated in both elements.

No.	Star.	AR.	PD.	No.	Star.	AR.	PD.
19	LL 892 WB (1) o, 484	−0·0112	+0·2342	366	LL 22450 WB (2) xi. 925	−0·0074	+0·1567
29	„ 892 Robinson 110	0·0087	0·2440	368	„ 22532 „ (2) xi. 990	+0·0053	−0·1212
35	„ 1912 WB (2) o, 1478	0·0088	0·1307	383	„ 23018 „ (2) xii. 199	−0·0037	0·1896
49	„ 4296 „ (2) ii. 270, 1	0·0039	0·1375	385	„ 23195 „ (2) xii. 338	+0·0146	0·1294
55	„ 4681 „ (1) ii. 399	0·0183	0·0937	389	„ 23312 „ (1) xii. 334	−0·0211	+0·0817
79	„ 6275 „ (1) iii. 278	0·0101	0·3102	390	„ 23334 „ (2) xii. 440	+0·0020	0·1418
84	„ 6634 „ (1) iii. 506	0·0019	−0·1474	393	„ 23422 „ (2) xii. 512	−0·0022	0·1356
101	„ 7683 „ (2) iii. 1318	0·0020	+0·1288	407	„ 23858 „ (2) xii. 830	0·0009	−0·1317
109	„ 8103 „ (2) iv. 271	0·0063	0·1265	410	„ 23954 „ (1) xii. 751	0·0404	+0·0762
110	„ 8171 „ (2) iv. 303	0·0028	0·1113	417	„ 24243 „ (2) xii. 1086	0·0046	0·1245
145	„ 9769 „ (2) v. 111	0·0098	−0·1376	438	„ 25288 „ (1) xiii. 600	0·0301	0·0479
150	„ 10011 „ (2) v. 385	0·0082	+0·1164	451	„ 26056 „ (1) xiv. 90	+0·0043	0·1148
180	„ 12296 „ (2) vi. 529	0·0364	0·1789	457	„ 26273 „ (1) xiv. 271	−0·0108	−0·1055
187	„ 12716 „ (2) vi. 909	+0·0045	−0·1631	459	„ 26391 „ (2) xiv. 414	+0·0048	+0·1475
194	„ 13198 „ (1) vi. 1320	0·0236	+0·1905	476	„ 27358 „ (2) xiv. 1182	0·0046	−0·1362
197	„ 13321 „ (2) vi. 1422	−0·0274	−0·1940	498	„ 28244 „ (2) xv. 496	0·0080	0·1132
204	„ 13849 „ (2) vi. 1906	0·0094	+0·4541	510	„ 28910 „ (2) xv. 1126, 8	0·0050	+0·1648
227	„ 15136 „ (1) vii. 1184	+0·0074	0·1286	512	„ 29070 „ (1) xv. 972	−0·0244	−0·0371
228	„ 15204 „ (2) vii. 1200	−0·0058	−0·1109	527	„ 30271 „ (2) xvi. 947	+0·0014	+0·4763
232	„ 15335 „ (2) vii. 1293	0·0182	+0·2322	538	„ 30694 „ (1) xvi. 873	−0·0439	1·5790
248	„ 16378 „ (2) viii. 323	0·0122	−0·1440	548	„ 31022 „ (1) xvi. 1062	0·0037	0·1025
262	„ 17081 „ (2) viii. 835, 6, 7	0·0030	+0·2765	549	„ 31099 „ (2) xvi. 1789	+0·0066	−0·1137
268	„ 17528 „ (2) viii. 1137, 8	0·0031	0·2078	559	„ 31523 „ (2) xvii. 341	0·0066	0·1576
270	„ 17750 „ (2) viii. 1294	0·0187	0·1285	571	„ 32256 „ (2) xvii. 1072	−0·0020	0·1366
279	„ 18159 „ (1) ix. 76	0·0046	−0·1054	574	„ 32333 „ (2) xvii. 1159	+0·0011	+0·1257
294	„ 18966 „ (2) ix. 686	0·0054	+0·1947	586	„ 32921 „ (2) xvii. 1635	0·0041	−0·1584
302	„ 19371 „ (2) ix. 980	+0·0184	−0·0841	607	„ 34319 „ (1) xviii. 611	0·0008	0·2046
308	„ 19635 „ (2) ix. 1191	−0·0161	0·1052	611	„ 34497 „ (2) xviii. 872, 3	0·0147	0·2166
311	„ 19782 „ (1) x. 6	0·0158	+0·0373	617	„ 34754 „ (2) xviii. 1091, 2	−0·0021	0·1460
324	„ 20483 „ (1) x. 486	0·0016	0·1182	632	„ 35445 „ (2) xviii. 1610	0·0024	0·3009
336	„ 20937 „ (2) x. 945	0·0049	0·1422	634	„ 35473 „ (1) xviii. 1355	+0·0022	0·1069
345	„ 21418 „ (2) xi. 73, 4, 5	0·0222	0·1355	640	„ 35821 „ (2) xviii. 1906	−0·0165	+0·1690
353	„ 21846 „ (2) xi. 397	0·0013	0·1659	665	„ 36785 „ (2) xix. 625	+0·0091	−0·1185
356	„ 22098 „ (1) xi. 561	0·0056	0·8994	676	„ 37019 „ (1) xix. 668	−0·0165	+0·0958
365	„ 22436 „ (2) xi. 917, 8, 9	0·0050	−0·1766	677	„ 37064 „ (2) xix. 816	0·0053	0·2131

No.	Star.	AR.	PD.	No.	Star.	AR.	PD.
704	LL 37994 WB (1) xix. 1247	−0·0026	+0·1095	843	LL 42295 WB (1) xxi. 847	−0·0114	+0·1066
705	„ 38063 „ (2) xix. 1649	0·0273	0·0025	852	„ 42594 „ (2) xxi. 1069	+0·0041	−0·1125
706	„ 38088 „ (2) xix. 1671	0·0052	−0·1142	855	„ 42713 „ (2) xxi. 1153	−0·0088	+0·1501
709	„ 38100 „ (1) xix. 1300	0·0208	+0·3331	900	„ 43751 „ (2) xxii. 384	+0·0216	−0·1389
717	„ 38380 „ (2) xix. 1910	+0·048	0·4744	904	„ 43891 „ (2) xxii. 475	−0·0307	+0·0526
727	„ 38761 „ (1) xx. 134	−0·0185	0·2731	907	„ 44035 „ (2) xxii. 547	0·0027	0·1347
737	„ 39108 „ (1) xx. 345	0·0241	0·0207	908	„ 44019 „ (1) xxii. 519	+0·0188	−0·0555
754	„ 39644 „ (2) xx. 920	0·0147	−0·0017	913	„ 44459 „ (1) xxii. 772	0·0058	0·3483
759	„ 39760 „ (1) xx. 754	0·0176	+0·0039	933	„ 45199 „ (2) xxii. 1359	0·0172	0·0720
764	„ 39923 „ (2) xx. 1135	0·0123	0·1241	935	„ 45241 „ (2) xxii. 1378, 9	0·0139	+0·0305
779	„ 40405 „ (1) xx. 1211	0·0012	−0·1091	950	„ 45780 „ (2) xxiii. 315	−0·0144	0·0939
780	„ 40450 „ (1) xx. 1240	0·0167	0·0672	952	„ 45829 „ (2) xxiii. 351	0·0176	−0·0534
793	„ 40788 „ (2) xx. 1756	0·0027	+0·0991	970	„ 46482 „ (2) xxiii. 791	0·0034	+0·1462
817	„ 41610 „ (2) xxi. 404	0·0056	0·1275	976	„ 46640 „ (2) xxiii. 881	0·0172	0·1300
823	„ 41723 „ (1) xxi. 461	0·0126	0·0648	984	„ 46803 „ (2) xxiii. 971, 2, 3	+0·0023	0·1109
840	„ 42213 „ (1) xxi. 789	0·0160	−0·0185	989	„ 46911 „ (2) xxiii. 1020	−0·0304	0·0491
842	„ 42310 „ (2) xxi. 869	0·0093	+0·1102	996	„ 47148 „ (1) xxiii. 1143	0·0002	0·1371

COMPARISON OF ARMAGH CATALOGUE WITH SCHJELLERUP.

No.	La Lande.	Armagh. — Schjellerup.		No.	La Lande	Armagh. — Schjellerup.		No.	La Lande.	Armagh. — Schjellerup.	
76	6079	$-0^{s}{\cdot}23$	$+1''{\cdot}47$	479	27507	$+0^{s}{\cdot}15$	$+3''{\cdot}05$	694	37504	$+0^{s}{\cdot}08$	$-59''{\cdot}61$
84	6634	+0·08	1·78	489	27950	0·14	0·08	707	38084	−0·06	0·14
139	9489	0·16	1·12	512	29070	0·08	1·91	709	38100	0·03	+4·19
254	16663	0·04	2·62	517	29545	−0·03	0·47	733	38995	0·05	1·83
260	17007	0·06	4·34	528	30256	+0·12	3·60	734	39023	+0·09	1·76
271	17802	0·14	−0·74	530	30345	0·21	8·37	779	40405	−0·56	0·49
280	18216	−0·07	0·04	531	30464	0·07	0·62	780	40450	0·18	1·44
293	18921	+0·21	0·13	534	30568	0·29	9·09	792	40755	+0·54	2·91
322	20357	0·08	+1·83	537	30671	0·22	9·10	796	40826	−0·04	1·83
324	20483	−0·15	0·32	538	30694	−0·55	+13·55	833	42054	+0·30	2·49
331	20642	+0·09	1·65	543	30864	+0·17	−1·93	840	42213	0·04	−1·43
338	21030	0·16	3·64	558	31494	0·00	0·29	861	42846	0·06	+1·51
373	22634	0·02	1·65	562	31741	−0·02	0·81	863	42875	0·27	−0·04
387	23252	−0·03	2·01	566	31849	+0·16	+1·84	866	42963	−0·01	+0·36
392	23381	0·04	3·61	577	32422	0·26	2·82	872	43142	+0·19	1·13
410	23954	+0·40	−0·13	579	32509	0·12	0·64	885	43392	0·06	1·33
411	23967	−0·02	+1·86	581	32633	−0·09	0·87	889	43518	−0·02	0·93
414	24155	+0·03	−0·13	593	33493	+0·10	1·38	897	43650	0·08	1·85
420	24294	0·02	+0·12	606	34218	−0·05	−0·12	906	43974	+0·08	4·07
422	24333	0·46	2·04	613	34632	+0·66	0·21	926	44939	−0·11	1·45
440	25380	0·30	1·91	614	34636	0·15	+0·59	942	45469	+0·05	2·82
451	26056	0·41	3·62	622	35005	0·11	−0·51	962	46117	0·08	2·71
455	26200	0·02	0·60	660	36489	−0·02	+2·21	968	46229	0·11	2·86
457	26273	−0·01	1·00	669	36813	+0·08	0·73	980	46742	0·00	2·68
462	26492	0·01	0·74	670	36890	−0·05	1·00	996	47148	0·31	4·20
463	26594	0·03	−0·02	679	37057	0·01	0·85				

CONCLUDING REMARKS.

No.	Stars.	
43	LL 2996	La Lande 1^m too small in AR.
55	„ 4681	B.A.C. 776. Radcliffe has $30''.40$ (70·06) in PD.
123	„ 8789	This star is WB 714 and 735 if 1^m be taken from latter.
146	„ 9827	WB probably out 60″ in PD.
201	„ 13648	WB probably out 60″ in PD.
204	„ 13849	La Lande is 35″ too small in PD by comparison with WB 1906.
258	„ 16933	WB probably out 60″ in PD.
323	„ 20453	La Lande 1^m too great in AR.
335	„ 20896	Radcliffe for 73·25 evidently 1^s too small in AR.
336	„ 20937	La Lande 1^m too small in AR.
342	„ 21300	WB probably out 10^s in AR.
368	„ 22532	La Lande assumed 5′ too great in PD.
392	„ 23381	Brussels observations just the mean of Schj. and Armagh.
		Brux $22''.12$ (69·30) and $21''.56$ (67·34) Schj. $19''.92$ (62·27).
500	„ 28318	The place of this star in PD differs about 5″ from WB and Radc.
627	„ 35334	La Lande 1^m too great in AR.
635	„ 35511	La Lande is 56″ too great in PD.
645	„ 35996	Radcliffe is almost $0^s.5$ greater in AR.
659	„ 36474	La Lande is almost 1^m too small in AR.
679	„ 37057	WB probably out 60″ in PD.
700	„ 37847	La Lande is $35^s.74$ too small in AR.
708	„ 38047	La Lande is 58^s too small in AR.
779	„ 40405	Schj. $25^s.56$ (62·660) Gött $24^s.85$ (67·620) Brux $24^s.95$ (71·706) & $24^s.89$ (72·728).
810	„ 41326	La Lande 10^s too small in AR.
826	„ 41814	La Lande 30^s too great in AR.
849	„ 42524	WB probably out 10^s in AR.
850	„ 42542	WB probably out 10^s in AR.
875	„ 43196	La Lande 1^m too small in AR.
876	„ 43250	La Lande 1^m too small in AR.
993	„ 47094	La Lande 30^s too small in AR.

TRANSACTIONS (NEW SERIES) VOLUME I.

(*Already Published.*)

PART.

1.—On Great Telescopes of the Future. By HOWARD GRUBB, F.R.A.S. (November, 1877.)

2.—On the Penetration of Heat across Layers of Gas. By G. J. STONEY, M.A., F.R.S. (November, 1877.)

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[FEBRUARY, 1880.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (NEW SERIES).

X.—*On the Possibility of Originating Wave Disturbances in the Ether by Means of Electric Forces.* BY GEO. FRAS. FITZGERALD, M.A., F.T.C.D. [Read November 17, 1879.]

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1880.

X.—ON THE POSSIBILITY OF ORIGINATING WAVE DISTURBANCES IN THE ETHER BY MEANS OF ELECTRIC FORCES.

BY

GEO. FRAS. FITZGERALD, M.A., F.T.C.D.

[Read November 17th, 1879.]

In Professor J. Clerk Maxwell's most admirable treatise on Electricity and Magnetism the following expression occurs—(§785) :—" Let us suppose that when t [time] is zero the quantities A and A are zero except within a certain space S," and he proceeds to show that this will give rise to an electrical disturbance propagated in free space with the velocity of light. Some doubt as to the possibility of producing a distribution of currents which would originate such disturbances was aroused in my mind by the following consideration: for the validity of the deduction it is necessary that the whole space considered be non-conducting. Now, Gauss showed long ago that such a quantity as the potential of any system of attracting bodies cannot have a zero value throughout one part of space and another value in any other communicating part. The components of A, the vector potential of the electric current, are of the same form as the potentials of attracting bodies, and could not consequently fulfil the condition Professor Maxwell assumes. Though this does not include the case of currents distributed throughout space, such as the changes of electric displacement which Professor Maxwell supposes to be currents, yet, I believe, that the reasoning may be extended to this case also. Further, it has to be shown that no other possible assumed distribution would give rise to disturbances propagated in time throughout space.

If we investigate how such disturbances could be originated by combinations of currents and charges on fixed or moveable conductors and non-conductors it is in the first place to be observed that we may legitimately assume the conductors to be perfect conductors, for the heating of a conductor by an electric current, as far as it is a production of waves in the ether, is according to Professor Maxwell's hypothesis, one of the very things whose origin we want to find out, and as far as it is only an increased motion of matter is not related to the question in hand.

Now, if any system of conductors, moveable or fixed, could give rise to the production of disturbances propagated throughout space, in time the energy of the system would become gradually expended in the same manner as heat is when a hot body cools. Another effect of such a system would be, that at each point of space there would generally be a double action, one the direct inductive action

which Professor Maxwell never assumes to be propagated in time, and the other the effect of the wave on arriving at the point.

Now, if we consider the case of any system of perfect conductors and non-conductors, moveable or fixed, and charged in any way, and carrying any currents, the interactions of the various parts may be worked out, either upon the hypothesis of direct action at a distance, or upon Professor Maxwell's hypothesis of action through a medium. In the former method there is, however, no account taken of the non-conductor, nor are any variables representing it in any way involved; and yet, if we are dealing with perfect conductors, such a system would be, as regards energy, perfectly conservative, and so cannot be such as would give rise to a disturbance propagated throughout space in time like light.

I conclude from this that the origination of such disturbances is not a phenomenon of electric currents such as we have to deal with, but is connected with the relations of matter and ether, and this is probably an atomic interaction, as spectroscopic phenomena also seem to show and will be explained only when some workable hypothesis as to the nature of this interaction has been sufficiently investigated.

If direct action, at a distance, and Professor Maxwell's hypothesis of action through a medium, lead to the same results, as has been, I believe rightly, just now assumed, then we may assert a very general theorem concerning the displacement currents which Professor Maxwell assumes in the non-conductor, and one which I have not yet succeeded in proving directly—namely :— that however these may be produced by any system of fixed or moveable conductors charged in any way, and discharging themselves amongst one another, they never will be so distributed as to originate wave disturbances propagated through space outside the system.

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VOLUME II.

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THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (NEW SERIES)

XI.—*On the Relations of the Carboniferous, Devonian, and Upper Silurian Rocks of the South of Ireland to those of North Devon.* By Edward Hull, M.A., LL.D., F.R.S., Director of the Geological Survey of Ireland, and Professor of Geology, Royal College of Science, Dublin. With Plates IV. and V., and Woodcuts. [Read November 17, 1879.]

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1880.

XI.—ON THE RELATIONS OF THE CARBONIFEROUS, DEVONIAN, AND UPPER SILURIAN ROCKS OF THE SOUTH OF IRELAND TO THOSE OF NORTH DEVON. By EDWARD HULL, M.A., LL.D., F.R.S., Director of the Geological Survey of Ireland, and Professor of Geology, Royal College of Science, Dublin. With PLATES IV. and V., and WOODCUTS.

[Read November 17th, 1879.]

My subject appears to divide itself into two heads—1st, the geological age of the great group of rocks which forms the main portion of the southern highlands of Ireland, namely, "the Dingle or Glengariff Beds"; and 2nd, the relation which these and the overlying formations in the south of Ireland bear to those of North Devon. And having discussed these questions, I shall conclude this paper with an attempt to describe the palæo-physical geography of these districts, as indicated by the relations of the formations respectively.

I.—*Composition and Geological Age of the Dingle or Glengariff Beds.*

The rocks which rise into the highest elevations in the south-west of Ireland, both to the north and south of Dingle Bay, belong to the same great group to which the late Professor Jukes applied the names of "Dingle beds," or "Glengariff grits and slates." Although the lowest beds of the group which occur in the Dingle promontory do not appear to reach the surface amongst the mountain ranges which rise to the south of Dingle Bay, yet there is no necessity that two names should, on this acount, be applied to the same general group of strata; I therefore propose in this paper to designate the group by the name of "Glengariff beds" only, a name derived from that bold and rugged ridge which lies between Kenmare and Bantry Bays, in which these beds are well represented.

(*a.*) *Composition of the Glengariff Beds.*—The nature and composition of this great group has been so often described by previous writers that a brief account is all that is necessary here. Taken as a whole, it consists of three principal divisions, as follows :—

1. *Upper.* — Consisting of purple slates with bands of grit, and a fossiliferous conglomerate near the top ("Parkmore Point conglomerate").
2. *Middle.*—Consisting of massive green and purple grits, sometimes pebbly, and containing slaty and calcareous bands at intervals.
3. *Lower.* — Consisting of purple and variegated slates and flagstones, resting conformably at Dingle upon fossiliferous beds of Upper Silurian age.

The thickness of the whole of this great group of rocks may be taken at about 10,000 feet. They appear to be unfossiliferous, except for the occurrence of linear

plant-like markings, probably those of *fucoids*, and of some species of plants of the group of vascular-cryptogams which have been found near Killarney by the officers of the Geological Survey. The Parkmore Point conglomerate, which occurs near Ventry in the upper beds of the formation, contains marine shells, &c., of Upper Silurian age.* The shells are found in large pebbles of calcareous sandstone, apparently not far removed from their original sites, and therefore strongly suggestive of the age of the beds amongst which they occur.

(*b.*) *Geological Age of the Glengariff Beds.*—Owing to the absence of fossil evidence, the geological age of this group has been somewhat indeterminate. In the coast section of the Dingle promontory the beds may be seen graduating downwards in a perfectly conformable and unbroken manner into those of similar character which contain Upper Silurian forms. On this ground the late Sir R. Griffith, as far back as 1857, suggested that they were themselves of Upper Silurian age,† a view supported by the late Mr. John Kelly and other geologists; and they are thus represented in the edition of Griffith's map which was exhibited at the meeting of the British Association at Manchester in 1840, as we are informed by the interesting account of the progress of geological discovery in Ireland, given by the late President of the Royal Geological Society, the Reverend Maxwell H. Close.‡ There seems at present to be a general *consensus* of opinion in favour of this view, based upon the intimate relationship of the Glengariff beds with the fossiliferous Upper Silurian, as exhibited in the Dingle sections, and the extreme discordancy between these beds and those of the Old Red Sandstone and Conglomerate, as evinced by numerous sections in the same district. It is the view which I myself am inclined to adopt, not only on the grounds above stated but for additional reasons which I now proceed to state; namely, the apparent identity of the Glengariff beds with those which occupy the banks of Killary Harbour, and of which Mweelrea, the highest mountain in the west of Ireland, is formed.

The Mweelrea beds consist of a series of slates, massive greenish grits and conglomerates, the whole of great thickness. The highest beds, known as the "Salrock Slates," are found on the south bank of the Little Killary Bay and Killary Harbour, dipping towards the north, and broken off in that direction against the line of a great upcast fault, which ranges along the western limb of Killary Harbour in a N.N.W. direction.§ The base of the whole series consists of calcareous shales and grits with Llandovery fossils and massive conglomerates. Throughout the whole of this series, fossils of Upper Silurian age occur at intervals, and have been described by Mr. Baily, F.G.S.‖ Owing to the original irregularities of the sea bed (formed

* "Explanation" of sheets 160, 161, &c., of the maps of the Geological Survey, p. 24.

† "On the relations of the rocks below the base of the Carboniferous Series, &c." Brit. Assoc. Rep. 1857. Trans. of Sections, p. 67.

‡ Journ. Roy. Geol. Soc., Vol. V., 142.

§ Geol. Survey Map, sheet 84; and Horl. Sections, sheets 25 and 26.

‖ Expl. Mem. Geol. Survey, sheet 83 and 84, p. 26, &c.

of disturbed, metamorphosed, and denuded Lower Silurian rocks), strata of different horizons, belonging to the Upper Silurian series, come in contact with the former, according to locality. On a general review of the case, however, we may safely assert that the uppermost beds on the banks of the Killaries represent a portion of the Dingle and Glengariff beds. There are other resemblances, such as the occurrence in both districts (those of Dingle and the Killaries), of contemporaneous volcanic products, all tending to confirm the view of the identity in age of these formations. The corresponding series in the two districts may thus be represented:—

Representative beds of the Upper Silurian Series in Kerry, West Mayo, and Galway (Descending Order).

Kerry (including Dingle).	*West Mayo and Galway.**
3. *Upper Slate Series.*—Red and purple slates of Dingle Harbour, Kenmare, Sneem, &c.; 3,000 feet.	3. *Salrock Slate Series.*—Bright red slates, with grits, and a band of limestone, with fossils. Lingula, Pterinæa, Trochus, &c.; 3,000 feet.
2. *Glengariff Grits.*—Massive green and purple grits, sometimes pebbly, forming the mountains of Brandon, the Reeks, and of Killarney, Glengariff, &c.; about 8,000 to 10,000 feet.	2. *Mweelrea Beds*—Green and purple grits and conglomerates, with beds of slate and shale and contemporaneous trap rocks; 8,000 feet.
1. *Smerwick and Sybil-Head Beds.*—Lying at the base of the Dingle section. Purple, brown, and green sandstones, flagstones and shales.	1. *Owenduff Series* (Upper Llandovery).—Green and grey grits, sandstones, shales, &c., with fossils. Favosites, Orthis, Atrypa, Trochus; 2,000 feet.

II.—*Relations of the Glengariff Beds to the Old Red Sandstone and Carboniferous Beds.*

The highly discordant position of the Glengariff beds to the Old Red Sandstone and Conglomerate in the Dingle promontory is recognised by all observers, and is of a very striking and trenchant description.† But it has been denied, or else not generally recognised, that any such discordancy exists in the mountainous region lying along both shores of Kenmare and Bantry Bays. For myself, I had entertained for a considerable period a doubt as to the supposed conformity of the Glengariff beds to the south of Dingle Bay; but it was not till the year 1877 that I had a favourable opportunity for making a personal examination of this district. Having, in the summer of that year, made arrangements (with the concurrence of the Director-General) for a tour of investigation, I examined various sections throughout the promontory of Dingle, the districts of Killarney, Kenmare, Sneem, and Glengariff. In this tour I was accompanied by Mr. J. O'Kelly, M.R.I.A., and Mr. Alexander M'Henry, officers of the Geological Survey. The general result was that, both along the shores of Kenmare and Glengariff Bays, we found the clearest evidences of a great *hiatus* between the Glengariff beds and those which

* Expl. Mem. Geol. Survey, sheets 93, 94, &c., p. 15.

† Hor. Section of the Geol. Survey, sheet 15. "Explanation," sheets 160, 161, and 171.

immediately overlie them in those districts; resulting in the entire absence of the Old Red Sandstone at the base of the Carboniferous beds.*

In order to render the real significance of this condition of the formations apparent, it is necessary that we should clearly understand the succession of the beds as they occur in the south of Ireland. It is generally admitted, and the evidence seems conclusive, that from the base of the Old Red Sandstone and Conglomerate upwards into the Carboniferous Limestone, there is an unbroken (or at least conformable) series of beds, which may be arranged as follows :—

Descending Series of Formations; South of Ireland.

		Thickness.	
Upper Conformable Group.	*e.* Carboniferous Limestone, ...	2,500 feet.	Carboniferous Series.
	d. Carboniferous Slate, ...	1,000 ,,	
	c. Coomhola Grit series, ...	3,000 ,,	
	b. Kiltorcan Beds (or "Yellow Sandstone of Griffith,")	1,500 ,,	Old Red Sandstone.
	a. Old Red Sandstone, with base of conglomerate,	2,000 ,,	

(*Great Hiatus and Unconformity.*)

Lower Conformable Group.	Glengariff Beds,	Upper Silurian Series.
	Ludlow ,,	
	Wenlock ,,	
	Llandovery ,,	

From the above it will be seen that there are two great conformable groups of strata, between which the *hiatus* or unconformable gap occurs. Now, when it is found that the Glengariff beds are overlain (as at Kenmare) by the Carboniferous Slate (*d*), it must be in consequence of the absence of the underlying formations, *c*, *b*, and *a*, constituting a gap or *hiatus*. Again, when it is found that the Glengariff beds are overlaid (as at Glengariff, Coomhola-bridge, Dunmanway, &c.) by the Coomhola grit series (*c*), it must be in consequence of the absence of the underlying formations *b* and *a*; or, lastly, when, as in the districts of Cork and Blarney, we find the Glengariff beds overlaid by the Kiltorcan beds (*b*), it is clear that this is because the Old Red Sandstone (*a*) is not present; and it is only, in fact, in the Dingle promontory on the north-west of the district, and in the direction of Fermoy, Waterford, and Tallow on the east that the Old Red Sandstone is found resting upon the Glengariff grits and slates.† I now proceed to give a few illustrations of the relations of the beds above referred to :—

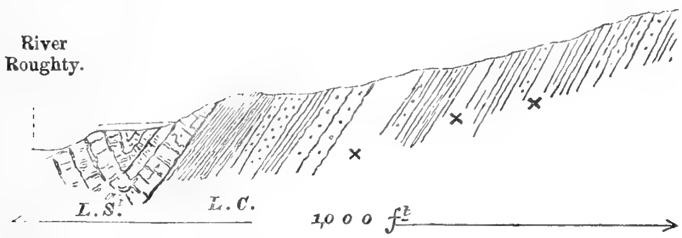
KENMARE DISTRICT (*a*), *Roughty Bridge.*—The beds of the Glengariff series, which rise along the slopes on both sides of the Kenmare River, consist of strong purple

* "On the Geological Age of the Rocks forming the Southern Highlands of Ireland, &c." Quart. Journ. Geol. Soc. Lond., Vol. XXXV., 699 *et seq* (1879).

† Though the re-survey of the south is still far from completion, we already know that the Glengariff beds stretch much farther east than the meridian of Cork, and may possibly be found entering the sea about Youghal Bay.

slates, with occasional beds of green and purple grit, enclosing the Lower Carboniferous slates and Limestone;—the Old Red Sandstone, Kiltorcan Beds, and the Coomhola Beds (either partially or altogether) being unrepresented. The accompanying section (Fig. 1) shows the succession of the beds.

Fig. 1.—*Showing the relations of the Glengariff and Carboniferous Beds at Roughty Bridge, Kenmare.*



L. S.—Carboniferous Limestone. *L. C.*—Carbs. Slates and Grits. *G.*—Glengariff Beds, consisting of purple sandy slate and greenish grits with quartz veins. ×—Spaces where strata are not shown.

The relations of these beds have been observed on the south bank of the Roughty River valley above the Bridge.

(*b.*) At Kenmare, between the suspension bridge and the village, we find purple and green slates with strong greenish grits, characteristic of the Glengariff Beds, at a distance of only 100 yards from the Carboniferous Limestone. The space over which the strata are not exposed is probably occupied by Carboniferous Slate.

(*c.*) At, and near, Sneem the relations of the beds are very similar to those above described. The section in the Tahilla River, above the Chapel, shows dark gray and blue slates, with Carboniferous fossils, succeeded by olive-coloured and greyish grits and slates of the Coomhola series in contact with beds of purple slate of the Glengariff series. There is an appearance of unconformity at the junction, where it is shown about 500 yards above the Chapel.* Higher up the stream are nearly continuous sections in hard purple or green grits, and purple slates.

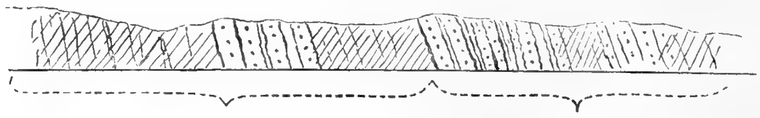
Amongst the hills in the direction of Sneem, the junction of the Lower Carboniferous Slate and Coomhola beds, with the purple slates of the Glengariff series, can be observed in numerous sections, and needs no further description. The above will suffice to show the nature of the hiatus as it occurs in the Kenmare valley.

Glengariff District.—The relations of the beds in the district of Glengariff generally resemble those at Kenmare. The massive purple and green grits, interbedded with strong purple slates, which rise into the rugged hills and precipitous crags to the north of the harbour, are succeeded by olive green and grey grits and slates of the Coomhola series. Sections are shown in the Coomhola River and

* A plan and section of this junction are given in the Quart. Journ. Geol. Soc., Vol. XXXV., p. 709, to which the reader is referred for more detailed information on the subject of the relations between the Glengariff and more recent formations.

other streams descending from the mountains, and the junction of the two formations may be clearly determined along the road from Glengariff to Bantry at a distance of about a mile and a half from the Church. (Fig. 2.) The dip of both formations appears to be similar.

Fig. 2.—Section along Road to Bantry, near Glengariff.

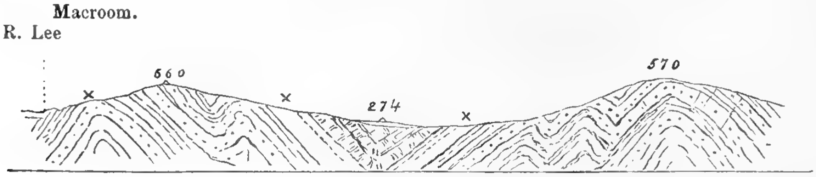


G. Glengariff Beds.—Purple rough slates and hard coarse green grits. *C. Carboniferous Beds.*—Grey and olive-green thin-bedded grits and rough slates.

I may here observe that although there must necessarily be some points of resemblance between two formations in juxtaposition, both consisting of alternating beds of grit and slate, both dipping at similarly (or approximately similarly) high angles, and both traversed by cleavage-planes, still the two groups have always certain points by which they may be distinguished. The Glengariff beds are generally massive, the prevalent colours are deep purple and sea-green, and the grits are coarse-grained. On the other hand, pale, greenish-grey, or olive-green colours prevail amongst the Coomhola beds, while the grits are thin-bedded and fine-grained. They also often contain marine fossils.

COUNTY CORK DISTRICT (*a*), *Macroom.*—To the south of the village there occurs a sharp synclinal trough in which lies the Carboniferous Limestone. (Fig. 3.) On either side the purple grits and slates of the Glengariff series form the flanks of the valley, but the junction of the Carboniferous Limestone is obscured by marshy ground. It is uncertain whether the limestone is directly in contact with the grits or separated therefrom by Carboniferous Slate. If the latter be present, it is only represented by 100–150 feet of strata. Here then the whole Coomhola grit series, which is of such thickness a few miles further south, near Bantry, is absent—together with the Old Red Sandstone. The hiatus is nearly at its maximum in this locality.

Fig. 3.—Section of Synclinal Axis south of Macroom, showing Carboniferous Limestone in close proximity to the Glengariff Beds.

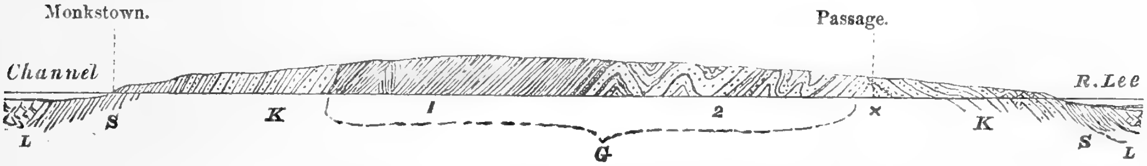


L. Carboniferous Limestone. × ×—Spaces where the strata are not shown. *G.*—Glengariff Beds, consisting of purple grits and slates—beds flexured.

(*b.*) In the neighbourhood of Coachford, Dripsey, and Blarney, the Carboniferous Slate, Coomhola grits, or Kiltorcan beds, are found respectively intervening between

the Carboniferous Limestone and the Glengariff slates and grits. At Timoleague, and south of Bandon, the Kiltorcan beds are in considerable force, but the main mass of the Old Red Sandstone is not represented. Similar conditions prevail in the district lying to the north-east and south of Cork, and I shall only refer to one other section, which has been very carefully measured by Mr. M'Henry, of the Geological Survey, because it not only illustrates the nature of the hiatus but also shows that the Glengariff beds are highly unconformable to those which are in contact with them. The section (Fig. 4) is taken along the side of Cork Harbour, between Monkstown and Passage :—

Fig. 4.—Section through Monkstown and Passage, showing unconformity between the Glengariff and Kiltorcan Beds—Distance about 3 Miles.



L.—Carboniferous Limestone. *S.*—Carbons. Slate and Coomhola Beds. *K.*—Kiltorcan Beds. *G.*—Glengariff Beds; 1. Upper Purple Slates, &c. ; 2. Purple and Green Grits and Slates. ×—Strata not seen.

By an examination of this section it will be seen that the Kiltorcan beds and Carboniferous Slate rest, in the direction of Monkstown, on Glengariff beds which are much higher up than those upon which the same formation rests in the direction of Passage. The beds at Passage are, in fact, from 2,000 to 3,000 feet below those at Monkstown—the former consisting *mainly* of purple and green grits, the latter *mainly* of purple slates, forming the upper division of the Glengariff series. It is not often that it is possible to obtain so clear an evidence of *unconformity,* although the evidences of the hiatus are everywhere plain and satisfactory. The above cases will probably suffice to illustrate the relations of the older and newer formations of the county Cork and adjoining districts of Kerry and Waterford, pending the publication of the revised maps of the Geological Survey.

III.—*Palæo-Physical Geography.*

These peculiar relations to each other of the two groups of unconformable strata are of interest as throwing light on the physical geography of the Palæozoic rocks in this part of Ireland. There is only one way, as it seems to me, in which these relations can be explained. To suppose that all these breaks as they occur throughout several hundreds of linear miles (often well seen in road and river sections) can be explained by the presence of faults dislocating the strata is out of the question. It is seldom that there is any evidence of fracture, or local disturbance at the points of junction where visible. On the contrary, the change from the purple slates or grits of the Glengariff series to Carboniferous beds is generally abrupt, decisive, and without fracture. The explanation of the absence of the formations must, therefore, be that they were never deposited ; in other words, that there was an

interval, more or less prolonged, during which there was an absence of sedimentary deposition in some localities while it was in progress in others; and this we can only account for by supposing that where no deposition took place the Glengariff beds formed dry land or shoal water.

Thus then, I infer that over the western and southern portions of Cork, and other districts where the Old Red Sandstone is absent below the Carboniferous beds, the Glengariff grits and slates had been disturbed and elevated into land surfaces until the Carboniferous period set in.

This inference is borne out by the fact that the Glengariff beds show signs of having been subjected to flexuring and foldings quite distinct from those which influence the Carboniferous strata, which latter are of later origin than the Carboniferous period; to these earlier disturbances I shall now refer more in detail.

IV.—*Contortions in the Glengariff Beds of earlier date than the Old Red Sandstone.*

As additional evidence of the unconformity between the Glengariff, and the Old Red Sandstone or Carboniferous beds, I may refer to the contortions into which the former are thrown, evidently differing in date as in direction, from those of succeeding formations. Throughout the county of Cork and adjoining districts the flexures of later date than the Carboniferous, and to which, consequently, all the formations older than the Carboniferous have been subjected, trend in approximately east and west directions. Owing to these post Carboniferous flexures the strata are thrown into the series of sharp foldings ranging in the directions stated, and it scarcely ever happens that Carboniferous beds or Old Red Sandstone dip otherwise than approximately north and south; but in the case of the Glengariff beds it is otherwise, for in many places amongst the mountains lying on the borders of Kerry and west of Macroom we find these beds contorted in directions which are approximately at right angles to the east and west flexures. This is very remarkable in the region bordering Lough Nambrackderg, where, throughout a distance of two miles measured across the strike, the general dip is westerly, at angles varying from 10° to 20.° Similar westerly dips are conspicuous amongst the massive grits lying to the north and west of the Coomhola River, and contrast strongly with the steady N.E. trend of the Lower Carboniferous beds* lying along the valley to the southwards. Such instances are strongly suggestive of disturbances of earlier date than, and independent of, those which have influenced the Carboniferous and Old Red beds; these latter, being of later date and more powerful, have tended to obliterate those to which the Glengariff beds have been subjected. The apparent conformity between the Glengariff and overlying Old Red, or Carboniferous beds, over large districts of county Cork, is capable of explanation if we suppose that the former were only

* These flexures are very carefully laid down on the field maps of the Geological Survey.

slightly disturbed prior to their re-submergence in Carboniferous times. It is quite possible to have two formations widely separated from each other in point of geological time lying actually conformable the one to the other. This may have been the case to some extent in the present instance, while at the same time a very wide gap and prolonged interval of time actually separates the formations. While, therefore, I admit the probability of an actual conformity in some places between the Glengariff and newer formations in county Cork, I deny the existence of a "continuous succession" of strata from the former to the later. Parallelism of bedding by no means necessarily supposes continuity of deposition.

Leaving this subject for the present, the question now arises, are there to be found in any other district strata which serve to fill up the *hiatus* described above as occurring between the Glengariff Beds and the Old Red Sandstone? and we naturally turn to Devonshire, where (as nearly all geologists are agreed) there is found to be an uninterrupted sequence of beds from the lowest Devonian up into the Carboniferous formations.*

V.—*North Devon Section.*

This section has very recently been described before this Society by the Rev. Professor Haughton,† and has been the subject of elaborate essays by several eminent geologists.‡ The late Mr. Lonsdale, while secretary to the Geological Society of London, came to the conclusion, that the series of fossils collected by Mr. Godwin-Austen and others from the South Devon limestones constituted a natural history group intermediate between those of the Silurian rocks on the one hand and of the Carboniferous Limestone on the other. This led to the establishment of "the Devonian system," by Sedgwick and Murchison.

It would be quite unnecessary for me to attempt a description of the rocks of Devonshire after all that has been written on the subject. I shall, therefore, only deal with them in so far as is necessary to establish the correlation of the beds with those of the south of Ireland, in a part of which correlation I have been anticipated to a certain extent by several writers, especially the late Mr. Salter, Professor Jukes, and Dr. Haughton. A great deal, however, still requires to be added in order to bring out in its full significance the analogies and differences in the succession of the beds in the two countries, which it is the purpose of this paper to elucidate. The following comparative section of the strata in the two districts under consideration is intended to give the reader a clear idea of their relationships. (See Plate IV.)

* After a careful consideration of the late Prof. Jukes' writings, and a personal examination of the North Devon section, I am unable to concur in his explanation of that section.

† Journ. Roy. Dub. Soc., Vol. II. (new series), p. 126.

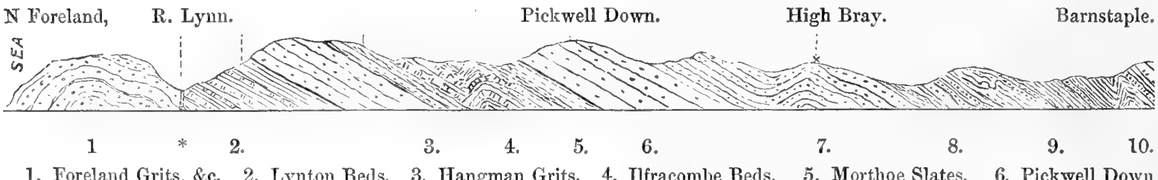
‡ Prof. Sedgwick and Sir R. J. Murchison, Brit. Assoc. Rep. 1836. Sir H. De la Beche, "Rep. Geol., Corn. and Devon and W. Somerset." Prof. Phillips, "Palæoz. Fossils of Corn., Dev. and W. Som." Prof. Jukes, Quart. Journ. Geol. Soc., Vol. XXII., 321. Mr. Salter, *Ibid.*, Vol. XIX., 474. Mr. Etheridge, *Ibid.*, Vol. XXII., 568; and Mr. T. Hall, *Ibid.*, Vol. XXII., p. 371, &c.

General Succession of the Carboniferous and Devonian Rocks.

	North Devonshire.	*South of Ireland.*
Lower Carboniferous Series.	Earthy limestone with Posidonomya (Benn Quarry).	Carboniferous Limestone.
	Barnstable Slates, ...	Lower Carboniferous Slate.
	Pilton Beds, ...	Coomhola grits and slates (with Cucullæa, &c.).
	Marwood Beds (Cucullæa zone), .	
Upper. Devonian.	Upcot Flagstones, ...	Kiltorcan Beds (with *Anodonta Jukesii*).
	Pickwell Down Sandstone, . .	Old Red Sandstone and Conglomerate.
Middle. Devonian.	Morthoe Slates, ...	Strata absent over the area of Ireland.
	Ilfracombe limestone group, . .	
	Hangman Grits (Martinhoe beds), .	
Lower Devonian, and Upper Silurian.	Lynton Slates and limestones, . .	
	Foreland Grits (base invisible), .	Glengariff Beds, passing down into Upper Silurian Beds.

The above table representing the consecutive series of the North Devon rocks, as recognised by nearly all writers on the Geology of this part of the British Isles —such as the late Sir H. De la Beche, Sir R. Murchison, Mr. Etheridge, Professor Haughton, and Mr. Townshend Hall, and which from a personal examination I am able to confirm, shows a threefold division of the Devonian formations below the Carboniferous beds of Barnstaple. As far back as 1855 Dr. Haughton recognised in the Pilton and Marwood beds with Cucullæa—the representatives of the Lower Carboniferous slate and Coomhola grit series of the south of Ireland,* and this view has been re-asserted by him more recently.† A similar view was adopted by the late Mr. Salter and Professor Jukes, so that we may feel satisfied of its correctness. But beyond this there is room for an additional step in the identification of the two sets of strata which, to my mind is equally satisfactory, namely, that of the Upcot Flagstones and Pickwell Down Sandstone with the Kiltorcan Beds and Old Red Sandstone and Conglomerate of the south of Ireland. A short description of the formations in descending order is all that will now be necessary, and the following section (Fig 5.) will give a general view of the succession of the beds.

Fig. 5.—Section through North Devon from North Foreland to Barnstaple, showing the succession of the Devonian, Old Red Sandstone, and Carboniferous Beds.



1. Foreland Grits, &c. 2. Lynton Beds. 3. Hangman Grits. 4. Ilfracombe Beds. 5. Morthoe Slates. 6. Pickwell Down Sandstone, and Upcot Flags. 7. Marwood and Baggy Beds. 8. Pilton Beds. 9. Barnstaple Slates. 10. Carboniferous Limestone. * Fault between Foreland and Lynton Beds.

NOTE.—According to the measurements made by Rev. Dr. Haughton, the thickness of the Devonian beds amounts to 9,600 feet (Journ. R. Geol. Soc. Vol. V., p. 126).

* Journ. Geol. Soc., Dub. Vol. VI., p. 227, &c.

† Journ. Roy. Dub. Soc. Vol. II. New Series, p. 126.

Brief Description of the North Devon Formations and their Fossils.

[Descending order.]

The fossils marked with an asterisk (*) occur in the Lower Carboniferous and Coomhola beds of the S. of Ireland, and have been identified by Mr. Baily, F.G.S. (Acting Palæontologist to the Survey.)

(*a.*) *Carboniferous Limestone* (Benn quarry).—Dark, thin-bedded earthy limestones and shales, dipping S. at 50°–60°. Fossils—*Posidonomya Becheri.*

(*b.*) *Carboniferous Slate.*—Dark schists (contorted) resting on light-grey slates, with calcareous nodules (Barnstaple slates). Fossils—*Cyathocrinus distans, Spirifer laminosus, S. cuspidatus, Streptorhynchus crenistria, Chonetes Hardrensis, Bellerophon decussatus, Productus costatus,* and *Phillipsia seminifera.*

(*c.*) *Pilton Beds.*†—Beds of grey, blue and purplish slate and grit, with thin calcareous bands. Principal fossils.—*Chonetes Hardrensis,* Productus prælongus, P. scabriculus,* Spirifera Urii, Rhynchonella pleurodon,* Orthis interlineata, Strophomena rhomboidalis * (analoga), Spirifera disjuncta,* Streptorhynchus crenistria, Cucullæa amygdalina,* Sanguinolites complanatus, Euomphalus serpens,‡ Orthoceras cinctum,* Actinocrinus tenuistriatus, Cyathocrinus variabilis, Poteriocrinus fusiformis, Phacops latifrons,* Calamites and Sigillaria.

(*d.*) *Marwood Beds* or "*Cucullæa Beds.*"—Hard grey and greenish grits and slates, with calcareous bands containing fossils, principally as casts; the beds are contorted and thrown into an anticlinal fold N. of Braunton Church. Fossils—*Lingula squamiformis,* Avicula Damnoniensis,* Cucullæa amygdalina,* C. angusta, C. depressa,* C. Hardingii,* C. trapezium,* Cypricardia deltoidea, Sanguinolites minus, Natica* sp. *Pleurotomaria expansa, P. gracilis, Orthoceras imbricatum. O. tentaculare, Palæopteris Hibernicus* (Sloly quarry) Knorria, Sphenopteris, &c.

(*e.*) *Pickwell Down Sandstone.*—Immediately lying underneath the "Baggy Point" and "Marwood Beds," with *Cucullæa trapezium,* &c., are a series of yellowish and greenish flagstones and shales, seen near the village of Upcot, which from their position underneath the "Cucullæa zone" and similarity of appearance, I consider to be the representatives of the "Kiltorcan beds" of the south of Ireland with *Anodonta Jukesii* and *Palæopteris Hibernicus.* The Devon beds have not as yet yielded fossils; not being, in fact, very well laid open for such a purpose. To these beds succeed the "Pickwell Down Sandstone," consisting of red and purple sandstones, with occasional shaly bands in the upper part, and of greyish hard grits in the lower. These beds are well laid open in the railway section south of Ilfracombe, and they rise into dry, elevated downs, from whence their name is

† It will be observed that this fauna is essentially of a Carboniferous type, and is taken from the list given by Mr. T. M. Hall. (Quart. Journ. Geol. Soc., Vol. XXIII., p. 378.)

Out of 78 genera with 153 species, stated by Mr. Hall to have been found in the "Pilton" and underlying "Cucullæa beds," about 42 species are known to occur in the Carboniferous Slate and Coomhola Grits of the south of Ireland, and 20 species occur in the "Ilfracombe beds" (Middle Devonian).

‡ *O. cinctum* occurs, as far as known, only in the Carboniferous Limestone.

derived. The thickness of these beds is very considerable; but, owing to the occurrence of one or more flexures, it cannot be determined with accuracy. We may assume it to be somewhere about 1,000 feet. Mr. Champernowne, F.G.S., has shown that this division is fully represented in South Devon, near Totnes.

(*f.*) *Morthoe and Ilfracombe Beds.*—The base of the Pickwell Down Sandstone is distinctly visible in a quarry by the side of the railway, south of Morthoe Station. The beds which underlie this formation consist of pale, grey micaceous slates, the materials of which might have been derived from the disintegration and denudation of gneissose or schistose rocks. These beds are unfossiliferous, and are followed in descending order by the Ilfracombe shales, slates, and limestones forming the important fossiliferous beds of the Middle Devonian group. These beds are laid open, not only in the fine coast sections at Ilfracombe, but also at Combe Martin, Watermouth, Widmouth, and Hagginton. According to Mr. Etheridge, this group has yielded 73 known forms, of which 35 (or 46 per cent.) are known in the corresponding beds of the Rhine, Belgium, or France; and only 8 species are known to pass upwards into the Carboniferous rocks of any area, viz.:—1 Gasteropod (*Acroculia vetusta*), 1 Polyzoon (*Fenestella antiqua*), 5 Brachiopods, and 1 Cephalopod (*Orthoceras cylindraceum*).*

(*g.*) *Hangman Grits.*—From beneath the Ilfracombe beds the great arenaceous formation called "The Hangman Grits," or "Martinhoe Group," (T. Hall) are seen to emerge in the cliffs of Combe Martin Bay, which are succeeded in turn by the Lynton slates and earthy limestones forming, with the underlying Foreland grits, the Lower Devonian and passage beds into the Upper Silurian Series.

(*h.*) The Lynton beds being fossiliferous are of special interest, and are strikingly laid open in the Valley of Rocks, where they form castellated tors and sharp crags which have been broken off along the faces of two intersecting systems of joint-planes. About 40 species of marine forms have been obtained from these beds, of which only 3 are known to pass up into the Carboniferous, viz.:—*Cyathocrinus pinnatus, Fenestella antiqua,* and *Chonetes sordida;* while out of 1,154 species known in the British Silurian, only one (*Atrypa reticularis*) is considered by Mr. Etheridge to occur in the Lower Devonian, beds. Such are the palæontological relations of the Devonian group of rocks to those which both precede and follow it.

(*i.*) *Foreland Grits.*—Lying at the base of the whole Devonian Series of North Devon occurs a remarkable group of rocks, because more antiquated in appearance than any of the grits or sandstones above described, and also because they bear a strong resemblance to the Glengariff Grits of the south of Ireland. These rocks are laid open to view in the cliff sections east of Lynmouth, and at Minehead. Their base is unseen, because (as has been shown by Sir H. De la Beche, and more

The Rev. Dr. Haughton states that whitish sandstones, resembling the Kiltorcan beds, are well shown in a quarry at Oakhampton, on the southern outcrop of the beds.

* Quart. Journ. Geol. Soc., Vol. XXIII., p. 639. No less than 235 species are enumerated by Mr. Etheridge as occurring in the Middle Devonian beds of South Down. *Ibid.*, p. 651.

recent writers, including Rev. Dr. Haughton,) they are thrown into the form of an arch, one limb of which dips under the sea, the other below the Lynton beds. Under the guidance of Mr. Ussher, F.G.S., of the Geological Survey, I examined the fine section laid open in the coast cliff, about a mile west of Minehead, and was greatly struck with the likeness between the rocks there forming the coast, and those belonging in some places to the Glengariff Series in county Cork.*

The Foreland Grits consist of deep purple and greenish-grey grits and quartzites, sometimes massive and coarse-grained, at other times flaggy and lenticular, and containing bands of reddish slate or indurated shale. Pebbles of quartz, quartzite, and banded slate are scattered through the rock, which is perforated by annelid burrow-holes. Mr. Ussher pointed out to me linear plant-like markings very much resembling those of the Glengariff slates; and, on the whole, I became, at the time of my visit, strongly impressed with the resemblance, and probable identity, of the Foreland beds to those of that formation.

There is besides strong presumptive evidence in favour of this view when we consider the geological position of the Foreland Grits. It has been shown that they lie at the base of all the Lower Devonian fossiliferous beds. Now, although the relationship of the Devonian to the Upper Silurian formations is unknown, and undiscoverable in North Devon, we cannot be far wrong in assuming the lowest Devonian beds to be at or near the position of the Uppermost Silurian. If the Foreland Grits form the connecting link between the Devonian beds and the Silurian, the Glengariff Grits and Slates form the connecting link between the Silurian and the Devonian.† They are thus brought very nearly on to the same geological horizon; and this, combined with their petrographical resemblances, leaves very little doubt in my own mind that they are really representative sets of beds.

VI.—*Lower and Middle Devonian Beds absent in Ireland.*

In describing the succession of beds in descending order, as they occur in North Devon, we were able to recognise the similarity of the beds to those of the south of Ireland as far down as a certain stage in the series, namely, to the base of the Pickwell Down Sandstone. We were able to recognise in the Barnstaple Slates the equivalents of the Lower Carboniferous Slate; in the Pilton and Marwood beds the equivalents of the Coomhola grits and slates; in the Upcot Flags those of the Kiltorcan beds, and in the Pickwell Down Sandstone those of the Old Red Sandstone. But at this point our identification ends, and we can nowhere find in the Irish area any representative whatever of the fossiliferous Ilfracombe series of the Middle Devonian, nor of the Lynton series of the Lower Devonian. As I am unable to accept Professor Jukes's interpretation of the problem, according to which

* Professor Jukes alludes to these rocks, and identifies them with "The Old Red Sandstone" rising from below the Lynton Rocks, which he considered to be "Carboniferous Slate." *Supra cit.*, p. 351.

† This is the view I have stated in my paper on "The Dingle Beds, &c." *Supra cit.*, p. 721.

the Ilfracombe and Lynton beds are those of the Lower Carboniferous series repeated by faults,* so I am equally unable to accept Mr. Etheridge's view that they are represented by the Dingle and Glengariff Beds.† Against the former view we have not only the palæontological evidence (which to my mind is conclusive) that the Ilfracombe beds cannot be the equivalents of the Marwood, Pilton, and Barnstaple beds, but we have also the undoubted superposition of the Pickwell Down Sandstone on the Morthoe slates, as seen near Morthoe station,‡ and Exmoor.§ Against the latter we have the extreme difficulty of supposing that a highly fossil-bearing group of strata of great thickness in Devonshire could be represented by an unfossiliferous group of great thickness and of different mineral characters in the closely adjoining district of the south of Ireland. It is not till we reach the bottom of the whole series that we really meet with the representative beds in Devonshire, but the overlying fossiliferous beds have really no representatives over the Irish area. It is here, in fact, that the great hiatus occurs, owing to which the Old Red Sandstone is everywhere unconformable upon whichever formation it happens to rest. Thus it is that the missing chapter between the Silurian and the Carboniferous in the palæontological history of Ireland is supplied by the rocks of Devonshire with their teeming populations of marine organisms, and the Devonian rocks assume their true proportions in the geological series of the British Isles, and offer a key to unlock one of the problems of Irish geology.

VII.—*Geographical Considerations.*

The whole subject we have been considering forces upon our view a remarkable series of changes of land-surface and sea-bed;—successive phases of elevation and depression of the southern portions of the British Isles, which I shall now attempt briefly to point out.

The Upper Silurian rocks appear to have been deposited in depressions and valleys formed out of the Lower Silurian rocks which had been disturbed, elevated, sometimes metamorphosed, and greatly denuded at the close of the Lower Silurian period.‖ Upon the re-submergence of the land at the commencement of the Upper Silurian period beds of conglomerate, breccia, grit, and slate were formed during the "Upper Llandovery" period—to be followed by finer sediments, sometimes with calcareous bands, and terminating upwards with the great group of rocks we have described under the name of "Glengariff" or "Dingle Beds." The maximum depression of the sea-bed in the south-west of Ireland must have amounted to nearly 20,000 feet; that is to say, an amount more than sufficient to bring the summit of the Alps to the level of the sea. The amount of the depression was probably much

* Professor Jukes only assumed the existence of one repeating fault, but it seems to me that to account for the Lynton Beds, according to his view, two are necessary. † *Supra cit.*, Table XII., p. 698.

‡ *Supra*, p. 146. § Mr. Ussher, Geol. Mag., February, 1879, p. 93.

‖ Physical Geology of Ireland, p. 21, *et seq.*

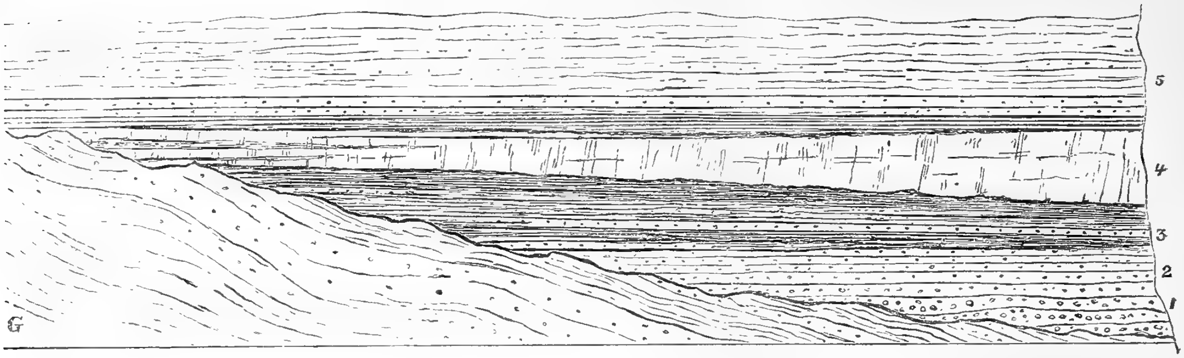
less in the centre and east of Ireland, where the Upper Silurian beds, including the Glengariff grits and slates, are absent. It is impossible to say to what extent this is due to denudation rather than to absence of deposition. A similar process of subsidence took place over the Silurian area on the Welsh borders—the North Welsh Highlands being a portion of the land of the period.

At the close of the period to which the Glengariff beds belong, the rocks over the region of the south-west of Ireland were disturbed and elevated into land, and so exposed to denudation; owing to which they are in a position of discordancy (as we have seen) to the formations which succeed them. Hence the hiatus in that region. It was otherwise, however, over the area of the south of England and Wales. *There* continuous depression appears to have gone on after the close of the Upper Silurian period, and during this depression the Lower and Middle Devonian rocks were formed in a sea thickly peopled by various forms of life over the Devonian area. Over the Welsh border area esturine conditions prevailed, owing to special physical causes which Sir H. S. De la Beche and Professor Ramsay have well explained. In this physical condition of the region of the south of Ireland we have a satisfactory explanation of the entire absence of the Lower and Middle Devonian beds, and it was only upon the commencement of the Upper Devonian (or Old Red Sandstone) epoch that the area of the south of Ireland partook of the general depression, and the lower flanks of the hills together with the plains were submerged.

As regards the submergence of the south of Ireland and Devonshire at this epoch, it is probable that the waters were esturine or lacustrine, as the presence of the fresh-water mussel, *Anodonta Jukesii,* in the upper beds of the Old Red Sandstone evinces conditions of this kind. But, over the Continental area, the conditions were probably marine, as the "Psamite du Condroz," which is the representative of the Pickwell Down Sandstone of Devonshire, and of the Old Red Sandstone of the south of Ireland is certainly a marine formation. The lacustrine conditions ultimately gave place to those of a marine character at the commencement of the Carboniferous stage, during which the area of the British Isles was continuously depressed, and the sea spread over the whole region, with the exception of a few elevated tracts which stood up as islands.* The Carboniferous materials were piled over the slowly subsiding sea-bed, climbing up along the flanks of the higher elevations as they were successively inundated; and it is not improbable that, at the close of the epoch of the Carboniferous Limestone, all the Upper and Lower Silurian hills were enveloped in Carboniferous strata. This gradual overlap of the Carboniferous beds during the submergence of the shelving-shore of Glengariff Beds is illustrated in the following woodcut (Fig. 6).

* In the Coal-fields of Great Britain, 3rd Edition, I have endeavoured to show on a map of the British Isles the submerged and land areas at the beginning of the coal period.

Fig 6.—Ideal Section showing the relations of the Glengariff Beds to those of later date in the S. of Ireland during period of maximum depression.



5. Upper and Middle Carboniferous Beds. 4. Carboniferous Limestone (thinning Westward) 3. Carbs. Slate and Coomhola Grits, &c. 2. Kiltorcan Beds. 1. Old Red Sandstone and Conglomerate. G.—Glengariff Beds.

The annexed map (Plate V.) is intended to illustrate those successive phases of the physical conditions of the districts now under review, and will, it is hoped, assist the reader in the attempt to follow the sketch I have endeavoured to give of these phases.

Thus closes what seems to me to be one of the most eventful chapters in the Geological History of Ireland.

EXPLANATION OF PLATE V.

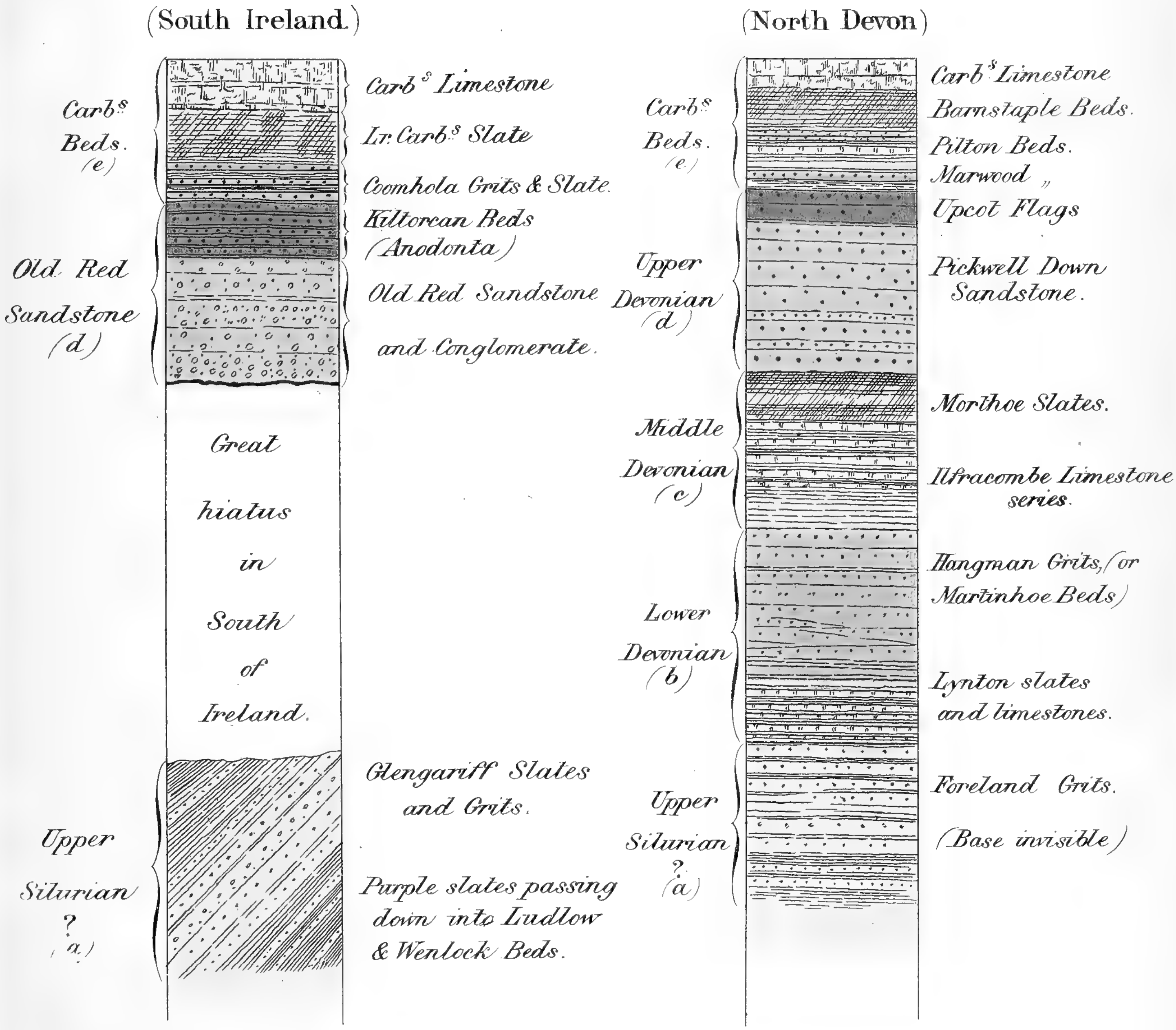
This plate is intended to illustrate the areas of elevation and submersion of the British Islands during four definite and critical periods of its palæo-physical history, intervening between those of the Lower Silurian on the one hand, and of the Coal-formation on the other. These are considered to be indicated approximately by the portions overspread by, or destitute of, the representative strata of each period, allowance being made for denudation.

The shaded portions show the areas over which the successive formations, namely, No. 1, the Upper Silurian (including the Glengariff Beds), No. 2, the Lower and Middle Devonian, No. 3, the Upper Devonian (or Old Red Sandstone), and No. 4, the Carboniferous Limestone were spread. The "Lower Old Red," of Scottish Geologists, is assumed to be the representative of the Glengariff Beds, and consequently of the Uppermost Silurian beds, though deposited in lakes or estuaries, and the areas embraced include Professor Geikie's "Lake Orcadie" and "Lake Caledonia."

The period of least submergence was that represented in Map No. 2, during which the Lower and Middle Devonian beds were being deposited. These beds are considered to be represented by the "Cornstone group" of Herefordshire and South Wales, deposited under somewhat different conditions (esturine) from those of the Devonshire beds, and are not to be found over the areas of the north of England, Scotland, or Ireland, which were probably land surfaces during this period.

The period of greatest submergence is that represented in Map No. 4, when there were land surfaces in the centre and east of England, and portions of Scotland and Ireland. The adjoining portions of France and Belgium are also included.

COMPARATIVE SECTIONS OF THE CARBONIFEROUS AND DEVONIAN SERIES OF THE SOUTH OF IRELAND AND DEVONSHIRE.



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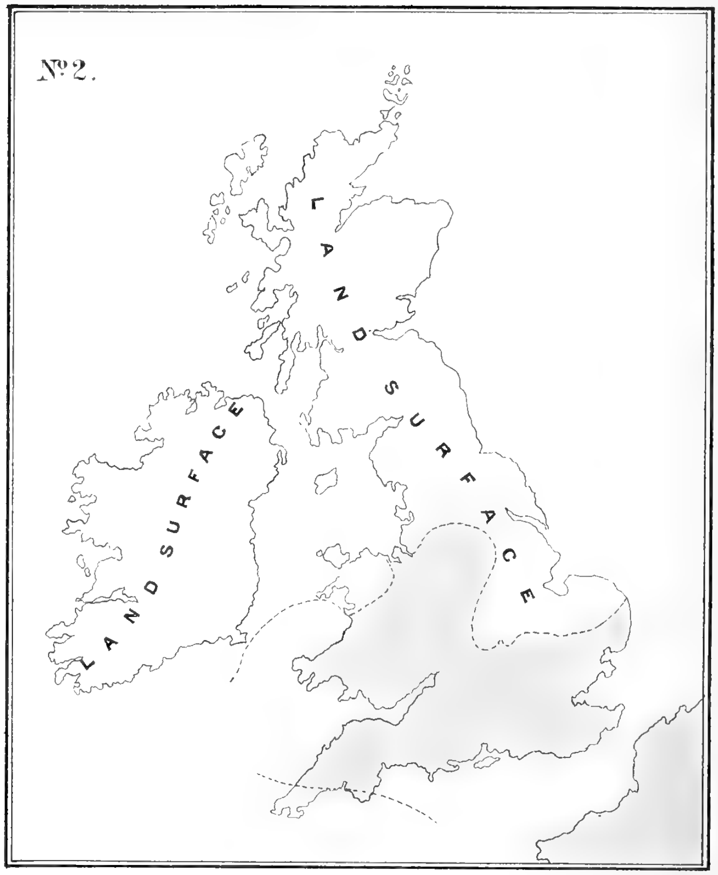

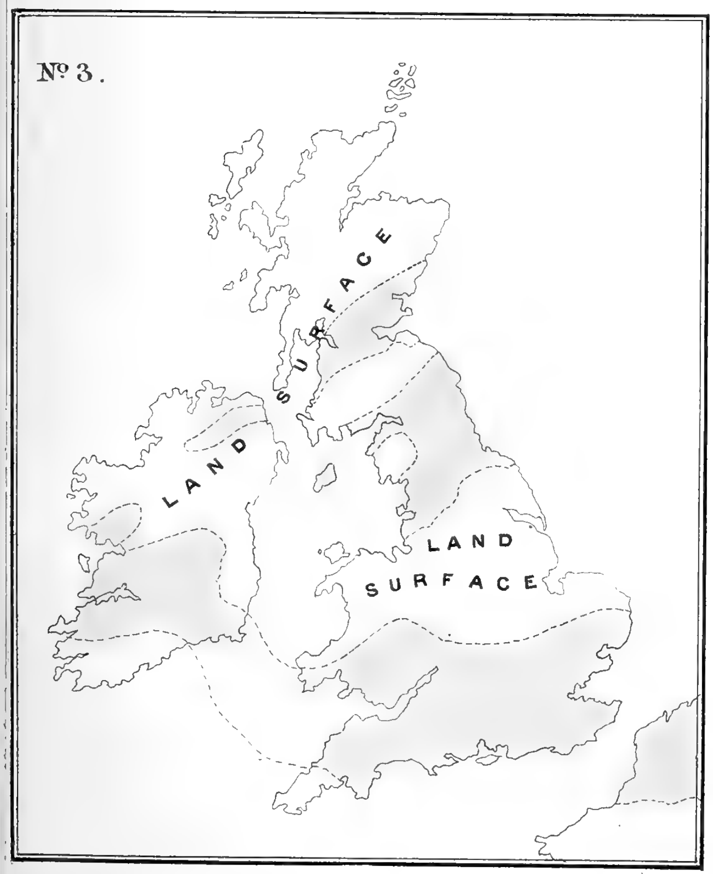

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XII.—PHYSICAL OBSERVATIONS OF MARS, 1879–80. By C. E. BURTON, B.A., M.R.I.A., F.R.A.S. With Plates, VI., VII., and VIII.

[Read February 16th, 1880.]

The series of observations here placed on record embraces a period of three months, from Oct. 5, 1879, to January 5, 1880, both days included; and, as the circumstances of observation were on the whole favourable for a careful scrutiny of the planet, I now venture to place the results before the Royal Dublin Society.

Instruments employed.—These were: (1) a 6 inch refractor made and equatoreally mounted by Mr. Grubb for my friend, Mr. J. H. Orpin, who has most kindly placed his instrument and observatory entirely at my disposal; (2) and chiefly, an 8 inch reflector (Newtonian) with concave specula of home make, mounted as an altazimuth on the plan adopted by Mr. John Brett, F.R.A.S., and described by him in the Monthly Notices of the Royal Astronomical Society, vol. xxxii. p. 294; and, (3) a 12 inch Newtonian, also of home manufacture, mounted as an equatoreal.

The magnifying powers employed varied according to the state of the air from 220 to 514 diameters, ascertained for each of the instruments by measurement of the diameter of the emergent pencil.

The powers found to work best with the reflectors were, for the 8 inch, triple achromatic objectives, giving amplifications of 220 and 380 diameters; and for the 12 inch, single lenses, magnifying respectively 408 and 514 diameters, were employed.

With the 6 inch achromatic, Huyghenian eyepieces yielding the approximate powers of 194 and 241 diameters were used, except on Dec. 24, when a new single lens eyepiece, magnifying about 270 diameters, was preferred to the equivalent Huyghenian.

It was the practice to insert on an outline disk the several details seen, as soon as their forms appeared with tolerable distinctness, then to add supplementary sketches of each detail on the same paper near to the principal drawing, if further scrutiny showed that modifications were necessary. When such supplementary sketches were made, the Greenwich mean time of taking each was appended to it. The Greenwich mean time of beginning and ending each group of sketches was also entered.

Explanatory notes were added to each sketch, where thought necessary. As soon as practicable, these detached sketches with the appended notes were used for

the compilation of a drawing embodying the results of the best views obtained during the period occupied by a group of sketches, and defined by the times given on the drawing. When possible, no one group of sketches was allowed to occupy more than half an hour, although when definition continued sufficiently good, two, or even three groups of sketches have been obtained in one night. Each of the drawings now laid before the Royal Dublin Society is a compilation made according to the method described above.

No comparisons with the results of other observers were made until each group of sketches was finished. Every detail when drawn was repeatedly compared with the image in the telescope. On each finished drawing is entered the longitude of the central point of the disc, computed for the middle instant between the times of beginning and ending by interpolation from the invaluable 'Ephemeris for Physical Observation of Mars,' published by Mr. Marth in vol. xxxviii., No. 8 of the Monthly Notices, and the drawings are numbered *in the order of increasing longitudes, not* according to their chronological succession. It was thought preferable to retain the same scale for the drawings as that employed for the series of views taken in 1871 and 1873, and published in the twenty-sixth volume of the Transactions of the Royal Irish Academy, although the planet's apparent diameter was considerably greater at the last than at the two previous oppositions just mentioned; for all the drawings are then directly comparable, while their dimensions appear sufficiently large to do justice even to the minutest details seen.

The atmospheric conditions were usually good, and the greater altitude of the planet in 1879 as compared with 1877, probably compensated observers in the northern hemisphere for its increased distance and diminished diameter. Some degree of confidence is therefore felt in the result of comparisons with the splendid series of drawings obtained by Mr. Green at Madeira, and by Mr. Dreyer at Parsonstown in 1877. These comparisons appear strongly to support the impression which seems now to be pretty generally entertained, that the great majority of the markings are permanent, and that differences of aspect are almost entirely due to altered projection (orthographic, with a variable axis), and where not thus explicable, they may usually be traced to temporary and partial obscuration by something in the nature of mist, frost, or snow, mainly dependent on the Martian seasons. Instances of such obscuration will be noticed when we come to the detailed descriptions of the drawings. In more than one case, drawings which ought to be duplicates differ noticeably in a way which is not accounted for by ascribing the discrepancy to errors of mere drawing, or the slight change of projection between the epochs of the sketches (see for example the sketches of Oct. 24, Dec. 1, and Jan. 5). The changes in the polar snows, especially in the northern snow spot, were very marked,* the very evident and large snow cap seen near the N. Pole having become very small and almost indiscernible between the beginning of

* See the Summary of Results, page 164.

October and the end of November. The sun had risen nine degrees higher with respect to Mars' northern hemisphere during this period. But the observed changes of the northern snow spot seem to indicate the existence of a variability dependent on the position of the Martian First Meridian, and attributable to non-coincidence of the centre of the spot with the North Pole of Mars. The drawings have all been made by eye estimations of the positions of the spots, without the aid of a micrometer.

Description of the drawings (*Vide* Plates VI. and VII.) :—

No. 1. Longitude of centre of disc=16·7° at $12^{h.}$ $20^{m.}$ G.M.T., on Oct. 25. The time given is that at which the original was finished. Observer : J. L. E. Dreyer, Esq., who has most kindly forwarded to me a copy of the drawing cited, together with his remarks thereon, for embodiment in this paper. The latter were as follows : "Mars in 12 in. Equatoreal. Power 300. Definition splendid. Clouds came on at $11^{h.}$ $57^{m.}$" (Dunsink mean time). "Markings near North Pole very easily seen. Bright spot* near limb, south following centre also. Dark line from centre towards the north certainly seen." The preceding remarks are extracted from the Observatory note book, those which follow were written on the original drawing. "Midway between centre and South Pole is a bright spot, oval p. and f. Canal to north very striking." This drawing affords most valuable support to those drawings made at Loughlinstown which represent the same phase or nearly so.

No. 2. Longitude = 26°. 1879, Dec. 1. $10^{h.}$ $26^{m.}$ to $10^{h.}$ $54^{m.}$ G.M.T. This drawing, like No. 1, includes the marking selected by Beer and Mädler as the origin of Martian longitudes, passing off towards the western limb. Near to it is shown a wedge-shaped space which nearly separates the spot just mentioned (Dawes Forked Bay) from that next following it, called by Proctor Beer Bay. Mr. Dreyer in No. 1 makes this separation complete, prolonging Phillips Island to the east and north until it joins Mädler Continent. The minute double point of Dawes Forked Bay was connected with the dark band surrounding the northern snow region by a narrow, slightly curved, dusky stripe. A similar, but oppositely curved dusky line, connects the point of Beer Bay with the border of the northern snow spot ; somewhat as Mr. Dreyer has drawn it. The form here given to the Strait of Herschel II., and its separation from the neighbouring shadings, impart to it an aspect intermediate between those under which it is represented by Messrs. Dreyer and Green in 1877. Arago Strait and De Cottignez Sea are evident, but between them there is a shaded streak which seems to be new to observation.

Between the two dusky stripes just mentioned as connected with Dawes Forked Bay and Beer Bay, is the place of Knobel Sea, the great dark pear-shaped marking

* Mr. Dreyer remarks on this, "I am not quite sure what this bright spot is. Probably it is the mouth of the bright streak south of centre."

shown in the drawings of many observers in the years 1869 to 1873, including Messrs. Terby, Knobel (after whom Mr. Green has named this marking), Green, and the author of the present notice. The marking in question was apparently concealed by snow or some analogous cause dependent on the Martian seasons, since it has, so far as I am aware, only been visible during the summer of Mars' northern hemisphere; although its latitude does not in itself militate against its being distinctly visible even during the midsummer of Mars' southern hemisphere.

Instrument: 8 in. reflector, with powers of 270 and 380, chiefly the former. Definition at times very good, showing the southern snow as a very narrow zone just detached from the limb at the middle of its length.

No. 3. Longitude = 28°. 1879, Oct. 24. $12^{h.}$ $13^{m.}$ to $12^{h.}$ $49^{m.}$ G.M.T. Almost the same aspect as that depicted in No. 2, but considerable differences in detail are evident. Phillips Island does not extend so far eastward as in the two previously mentioned drawings, and is not even imperfectly connected with the Mädler continent. Christie Bay, with some of the neighbouring markings is, however, distinctly visible. A white spot (a) is shown close to the western (W.) limb, nearly in the position of Hirst Island, this being the only occasion on which that spot appears to have been seen at the last opposition, though it was repeatedly detected in 1877. A dusky stripe, not seen in 1877,* runs north-westward from Christie Bay. The space about the South Pole is much lighter in this drawing than in No. 2, and displays much less detail. The dark markings were visible much closer to the eastern than to the western limb of Mars.

Instrument: 8 in. reflector, powers 220 and 270, the former being a triple achromatic combination giving exquisite definition.

No. 4. Longitude=36°. 1880, Jan. 5. $8^{h.}$ $18^{m.}$ to 9^{h} $0^{m.}$ G.M.T. The dusky stripes running northward from Dawes Forked Bay, and from Beer Bay were very distinct. A portion of another streak, of similar appearance, and directed from the neighbourhood of the North Pole towards Christie Bay, was seen. The two points of Dawes Forked Bay appeared as one, melting into the streak connected with them, while Beer Bay seemed to terminate in a defined point of darker shade than the stripe proceeding from it. A number of other minute details were seen by glimpses, too transient to permit their true form and disposition to be satisfactorily seized. They consisted chiefly of irregularities in the northern boundary of De La Rue Ocean following Beer Bay. The revelation of these was probably due to the increased aperture made use of on this occasion, namely, twelve inches of silvered glass, and a magnifying power of 408 diameters. Dawes' Forked Bay and Beer Bay are nearly separated by a kind of veil which almost reaches the east end of Phillips Island.

* Except by Schiaparelli. See summary, page 170.

No. 5. Longitude=47°. 1880, Jan. 5. $9^{h.}\ 18^{m.}$ to $9^{h.}\ 28^{m.}$ G.M.T. (*Unfinished.*) The limits of the completed portion are defined by the dotted line. The dusky stripe near the eastern limb is probably compounded of the two closely adjacent stripes formerly mentioned, (cf. No. 4.) Another streak dimly seen before has become very distinct near to the central meridian. It seems to connect the N.W. angle of Christie Bay with the dark zone near to the N. limb and to be probably identical with the streak shown in Nos. 1, 3, and 6, which occupied sensibly the same areographic position. At its northern extremity this streak was seen to join a similar one lying approximately on the parallel, and to form at the junction a triangular 'lake.' Both streaks were sharply defined at the edges under a power of 514 diameters, with which they presented a bluish green tint. Near the terminator details seemed to be rendered almost invisible by a kind of luminous veil, while they could be traced almost if not quite up to the preceding (the 'full') limb. The meridional streak shown in this drawing was far too distinctly seen to permit of my thinking that its true form had not been perceived with sufficient accuracy to render me certain that, even if it were not a continuous streak, the component parts were assuredly disposed lineally, and were individually very minute as compared with the length of the streak.* Definition was at moments beautifully sharp and clear, especially when No. 5 was made, until I was interrupted, and finally compelled to cease work, by misty clouds which came up from the south-westward. When No. 4 was begun, Lockyer Land was very distinct; so also was Phillips Island. The S. edge of Beer Continent was formed by a narrow and bright white stripe.

Instrument: 12 in. reflector with power 514.

No. 6. Longitude=48°. 1879, Oct. 24. $13^{h.}\ 45^{m.}$ to $14^{h.}\ 1^{m.}$ G.M.T. Christie Bay is fully displayed, notwithstanding its nearness to the limb. Neither on this occasion nor on the others on which this marking was visible, did it manifest itself under precisely the same form which it presented to Mr. Green in 1877, but appeared to approximate more nearly to the simpler outline attributed to it by Professor Kaiser and by Mr. Lockyer in 1862 and 1864, not to mention other more recent observers. The simpler outline is probably due to the inferiority of the climates or instruments in or with which the majority of observers have been compelled to work, when compared with those accessible to the eminent areographer just mentioned.

The continuity of the outline of De la Rue Ocean to the south-east of Christie Bay is interrupted by a white streak, the western portion of which conceals Hall Island. This white streak is evidently a cloud. It has been pointed out by former areographers that the region now under consideration is peculiarly subject to apparently non-periodic obscuration by luminous veils of limited extent and generally of brief duration, analogous as regards behaviour to our clouds but not,

* See summary, page 170.

as I fancy, so superior in brightness to the supposed continents as terrestrial clouds would probably appear under similar conditions. In my notes I have more than once remarked that such a temporary veil was not brighter, and, in one instance at least, was fainter, than the adjacent continent, nearly of the same tint of orange, and many shades fainter than the 'snow' spots. The extremely dark spot named Terby Sea by Mr. Green is shown for the first time in the present series, as well as its minute predecessor in rotation to which Professor Schiaparelli's name has been given by the same astronomer. The Terby Sea is almost, if not completely, put in connexion with De la Rue Ocean by a narrow dusky stripe.* The long dusky streak connecting Christie Bay and the North Polar regions reappears here. (See under No. 3). An extensive and ill-defined luminosity overspreads the marking called Jacob Land, as in No. 3 drawing. Very little detail was seen in the Antarctic Region. Eight-inch reflector, used with power 220, triple achromatic.

No. 7. Longitude=93°. 1879, Nov. 22. $9^{h.}$ $39^{m.}$ to $10^{h.}$ $1^{m.}$ G.M.T. Justifies the remarks made on the form of Christie Bay when describing No. 6. Schiaparelli Lake appeared more like a very short streak than a nearly circular spot. (N.B.—The definition was not at its best at this time.) The Terby Sea presented itself under a rudely rhomboidal form, not as an oval; which last shape it took when vision was not at its best and steadiest. It was estimated to be on the diameter passing through the northern snow spot and the centre of the disk at $10^{h.}$ $0^{m.}$ G.M.T.

Instrument: 8 in. reflector, usually with power 270.

The system of interlacing and interfused dusky streaks on the northern side of the Terby Sea is curious, but does not appear to be new. See Kaiser's work. No 'snow' could be detected with certainty at or near to the southern limb.

Bessel Lake (Green) was not visible, though the bay to the south† was very distinct.

Neither could Lagrange Peninsula be made out; a failure which was repeated whenever this region was well placed for close scrutiny.

No. 8. Longitude=103°. 1879, Dec. 24. $5^{h.}$ $40^{m.}$ G.M.T.

This is the first of a set of three sketches obtained, on the date above given, all of which present anomalous features by no means easy to account for. The Terby Sea appears as a dark elongated spot with a prolongation extending in a S.W. direction, while to the N.E. of the dark spot a distinct bay is represented in the drawing, which seems to include the Terby Sea with its appendages.

The explanation of these anomalies which appears at present to be the most probable one, is, that the streaks of shade on the northern and eastern sides of the Terby Sea were well defined at their outer edges, but not equally so on the side next the De la Rue Sea. If, moreover, there was a network of faint lines within the area thus enclosed, similar to that detected on Nov. 22, it would, at

* Previously discovered by Schiaparelli (1877). † This bay has been named Funchal Bay. See next page.

the greatly increased distance of the planet on Dec. 24, present the aspect of a general faint shading over the whole region traversed by the interlacing lines. The slightly diminished instrumental power employed on Dec. 24, would contribute to produce the effect observed. I find a note in the observing book to the effect that "vision" was "excessively difficult." Definition improved afterwards.

No. 9. Longitude=113°. 1879, Dec. 24. $6^{h.}\ 10^{m.}$ to $6^{h.}\ 23^{m.}$ G.M.T.

The remarks on No. 8 apply also to this drawing, but one or two details had become visible which were not seen before. The principal of these is the bay to the east of that described under No. 8, probably Pratt Bay (Green). Three white spots were seen at the limb, two at or near to the poles, the third at position angle 280°±10°.

Two faint dusky stripes were suspected to originate from the points of the two seeming bays, and to cross the equator into the northern hemisphere.

Instrument used for Nos. 8 and 9; the 6 in. achromatic, with a power of 270.

No. 10. Longitude=114°. 1879, Nov. 22. $11^{h.}\ 1^{m.}$ to $11^{h.}\ 30^{m.}$ G.M.T.

A much larger amount of detail is here shown than in No. 7, taken an hour and twenty minutes previously. Definition had improved, and was at times extremely hard and sharp with power 270 on the 8 in. reflector, and the beauty of the image was such as it has rarely been my good fortune to witness. The sketch was considered on the whole to be very faithful, and an exceptionally high value has been attached to it on account of the favourable circumstances under which it was made.

The Terby Sea was undoubtedly *rhomboidal* in form, and was nearly surrounded by what appeared to be a system of interlacing streaks connecting it on the south side with various portions of the De la Rue Sea, and on the north with an almost continuous streak which joined Christie Bay with Pratt Bay or its neighbourhood. Near the middle of the last-mentioned streak, at its confluence with a minute dusky stripe connected with the Terby Sea, I detected a very minute 'lake,' which seems, however, to be too far to the north to be identified with Bessel Lake (Green). The bay to the south of Bessel Lake is very dark and distinct. I venture to propose for it the name of the *Bay of Funchal* in remembrance of Mr. Green's labours at Madeira.

Lagrange Peninsula was on this occasion as on all others, quite invisible. The northern snow spot was at this time very faint, and none could be detected with certainty at the southern limb. Schiaparelli Lake well seen.

In the drawing the shadings east of Funchal Bay should be somewhat nearer to the Terby Sea.*

* The coast line east of Funchal Bay was very sharply defined.

No. 11. Longitude=117°. 1879, Nov. 18. $8^{h.}$ $55^{m.}$ to $9^{h.}$ $10^{m.}$ G.M.T. On this occasion the definition was most exquisite, with a power of 270 diameters on my friend Mr. Orpin's 6-inch achromatic, kindly placed by him at my disposal whenever Mars was badly situated for the use of my own instruments.

The Terby Sea was finely shown, with a *rhomboidal* outline, and darkest at its centre. It appeared to be of a dark neutral tint.

Bessel Lake was seen distinctly as a dusky speck in a streak proceeding northward from Funchal Bay. The form given to Funchal Bay differs somewhat from that which it has in Nos. 7 and 10, but not outrageously. I believe that the elongated dusky spot near the W. limb is Schiaparelli Lake, but from its position on the disk it would be hazardous to assert the identity of the two, though it may be considered probable. There are evident traces of the streak* separating Copernicus Land from Browning Land (Green.) A bright white speck was seen at the southern limb, but no snow spot could be detected at the northern, though a faint segment, somewhat lighter in tint than the neighbourhood, is shown on the drawing. Oudemann Sea is faintly indicated.

No. 12. Longitude=142°. 1879, Oct. 6. $10^{h.}$ $0^{m.}$ to $10^{h.}$ $35^{m.}$ ± G.M.T. Definition with the 6-inch achromatic and power 270, was exquisite. In this drawing Maunder Sea (Green) and Maraldi Sea (Proctor) are shown. The regularity of the northern edge of the latter is interrupted by a wedge-shaped light marking to the W. of Trouvelot Bay (Green), which was evidently of a temporary character, as it does not appear on older drawings, and was not seen again on any other occasion. A white speck was visible at or very near to the southern limb. The northern snow was very faint.

No. 13. Longitude=144°. 1879, Dec. 24. $8^{h.}$ $14^{m.}$ to $8^{h.}$ $42^{m.}$ G.M.T. This is the last of the three drawings made on this date as mentioned when describing No. 8. Terby Sea was not visible, which is not surprising, as it was about 60° from the centre of the disk at this time. The projection of Secchi continent southwards between Pratt and Trouvelot Bays was strongly marked, but the apex of the projection was somewhat ill-defined. Webb Land† was very distinct. The outline of Maraldi Sea was considered to be satisfactorily represented in the drawing. A great deal of detail was glimpsed which could not be drawn, on account of the fitfulness of the definition with the 12-inch mirror and power 408, though the relief to the eye produced by the increase of light and separating power was very decided. As on several former occasions, a dusky streak was seen, which originated at Trouvelot Bay, and traversed Secchi continent in a north-westerly direction. The narrow dark line near the S. Pole is merely intended to show the limit of the snow spot, and has no objective existence. Maraldi Sea was very

* Dawes Sea?

† Named by Mr. Green after the Rev. T. W. Webb.

sharply defined on the northern side, and faded away on the southern into the light ground there prevalent. There were some minute and indistinctly seen markings to the north of Pratt Bay.

No. 14. Longitude=153°. 1879, Oct. 6. $11^{h.} 5^{m.}$ to $11^{h.} 12^{m.}$ G.M.T. Trouvelot Bay is shown at mid-transit or nearly so. A remarkable system of interlacing dusky streaks diversifies the surface known as Secchi continent, slightly altered in form by the effect of rotation since No. 12 was drawn, but evidently identical with the similar system there depicted. Trouvelot Bay appears with a single point, there being no trace of Noble Cape (Green).

Instrument: no record in the observing book, but I believe that the 6-inch was employed in obtaining both Nos. 12 and 14, with power 400.

No. 15. Longitude=181°. 1879, Oct. 6. $12^{h.} 40^{m.}$ to $13^{h.} 20^{m.}$ G.M.T. Trouvelot Bay is shown near the W. limb, and Huggins Bay (Green), is appearing at the eastern. The north polar snow is faint, but the dark shade near it is narrow and distinct. Hooke Sea (Proctor), appears prolonged toward the W.S.W. by a narrow streak, probably a portion of Maunder Sea, the western end of which is not visible. Near Huggins Bay Herschel I. Continent is bordered with bright whiteness. The eastern portion of the streak system described under No. 14 is visible, and is joined by a streak * originating in the neighbourhood of Huggins Bay, represented in many later drawings. The 8-inch reflector was used, with power 270.

No. 16. Longitude=190°. 1879, Nov. 13. $10^{h.} 50^{m.}$ to $11^{h.} 10^{m.}$ G.M.T. Trouvelot, Bay, close to the western limb, was on this night seen to terminate in a double point. The detection of this minute feature was probably due to the planet being much nearer to the earth than on Oct. 6. Noble Cape seemed to be of greater length than in Mr. Green's map. Burchardt Land and Hooke Sea are just visible near the eastern (E) limb, and Oudemann Sea is plainly shown, connected with Huggins Bay by a faint undulating dusky streak. Another faint streak is shown in connexion with Trouvelot Bay (see observations of Oct. 6). Maunder Sea is very conspicuous, and a minute bright speck was seen at the southern limb, and inserted in the drawing. Close to the western limb a bright space was seen. The north polar snow was white and sparkling. Definition at times very fine, with power 270 on the 8-inch reflector.

No. 17. Longitude=211°. 1879, Nov. 11. $11^{h.} 15^{m.}$ G.M.T. Drawn by Mr. Dreyer, with the 'South' Equatoreal of the Dunsink Observatory. In the absence of original notes accompanying this drawing, kindly placed in my hands by Mr. Dreyer for embodiment with my own series in the same manner as No. 1 was, I venture to draw a few conclusions from the sketch itself. There are distinct traces

* Huggins Inlet (Proctor).

of the dusky streak which originates at Trouvelot Bay, shown in many of my sketches, and we may therefore consider that its real existence is placed beyond doubt. The streak proceeding from Huggins Bay is perhaps faintly indicated. Part of Oudemann Sea is visible, also Maunder Sea. Hooke Sea and Burchardt Land, as well as the southern snow spot, are distinctly shown; and Noble Cape is also well-defined.

No. 18. Longitude=212°. 1879, Nov. 11. $10^{h.}$ $59^{m.}$ to $11^{h.}$ $40^{m.}$ G.M.T. This drawing, made almost at the same absolute time as No. 17, differs from it in a remarkable manner, omitting the streak from Trouvelot Bay, and showing one which originates in the neighbourhood of Gruithuisen Bay (Green) and connects it with a diffused shade bordering the Arctic Circle. Huggins Bay and Oudemann Sea are connected by a dusky streak, the southern end of which is shown in No. 17. Maunder Sea is very distinct.

Fine definition with power 220 (an achromatic triplet) on the 8-inch reflector.

No. 19. Longitude=215°. 1879, Nov. 13. $12^{h.}$ $35^{m.}$ to $12^{h.}$ $52^{m.}$ G.M.T. The only feature of this drawing which requires particular notice is the streak running northwards from Gruithuisen Bay, already remarked upon. Hooke Sea is drawn too near the eastern limb. The boundary of the north snow spot was a very distinct dark line.

Same instrument used, and power 270.

No. 20. Longitude=216°. 1879, Dec. 17. $8^{h.}$ $42^{m.}$ to $9^{h.}$ $12^{m.}$ G.M.T. The same part of the planet is here presented to view at a date five weeks later than that of Nos. 18 and 21, and as seen with a much more powerful instrument, the 12-inch equatoreal reflector, furnished with R.A. movement, and armed with magnifying powers of 408 and 514 diameters. Definition was at times extremely fine with these powers.

Noble Cape is exceedingly distinct. Trouvelot Bay and Huggins Bay each form the origin of dusky streaks similar to, and probably identical with those already described. The latter streak was sharply defined on both sides. The southern side of Maraldi Sea was very ill-defined compared with the northern, which was hard and irregular. I could not seize the positions of the minute irregularities so as to draw them,* for they flitted into and out of sight very rapidly with the undulations of the air.

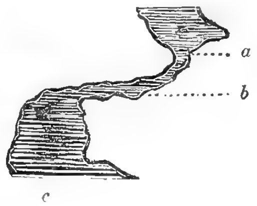
The northern snow was bounded by a dark and very narrow line,† repeatedly seen with power 514, and appeared very small and white. The shadings were visible closer to the western limb than to the terminator. The penumbral edge of the terminator was visible, of a bluish tinge, which, as I satisfied myself, was not due to the eyepiece. The preceding, or fully illuminated limb, appeared as sharp as the edge of a hole punched in metal. The streaks and the faint shading seen in the position of Oudemann Sea were decidedly blue.

* The general appearance is shewn in the Drawing.

† This line was not perfectly sharp, and was rather tangential to than concentric with the snow spot.

No. 21. Longitude=220°. 1879, Nov. 11. $11^{h.} 40^{m.}$ to $12^{h.} 0^{m.}$, G.M.T. Definition was at times very beautiful with the magnifying powers of 120, 220 (achromatic) and 270 on the 8 inch reflector, the planet appearing with a perfectly hard and clean outline, quite free from all trace of stray light. Nevertheless, I found it impossible to draw so as to satisfy myself, especially with regard to the exact form of Burchardt Land and of Gruithuisen Bay, on account of the continually recurring tremors, partly due to the furious wind prevailing at the time.

The faint streaks represented in Mr. Green's map as running southwards to Oudemann Sea and Delambre Sea respectively, were at times well seen, though they are badly drawn. The streak connecting Huggins Bay with Oudemann Sea appeared like a narrow greenish ribbon with sharply defined edges, and is rudely represented in outline in the annexed diagram, copied from one made in my journal at the time.



(*a.*) Huggins Bay. (*b.*) Huggins Inlet. (*c.*) Oudemann Sea.

Diagram showing the form of the streak above mentioned, which is identical with Huggins Inlet (Proctor).

Oudemann Sea was instantly recognised by its form, though its name was not known until the map was consulted after the night's work was finished.

No. 22. Longitude=233°. 1879, Nov. 10. $11^{h.} 55^{m.}$ to $12^{h.} 20^{m.}$, G.M.T. This drawing is remarkable for the apparent isolation of the W. end of Hooke Sea from the remainder of that marking by a patch of much lighter shade, visible on this night only, and consequently of a fugitive nature, probably akin to terrestrial clouds. A great number of minute details* were seen, which it was impossible for me to draw, as they were visible only by most transient glimpses. A faint streak connects Flammarion Sea (Green), with the dark arctic band. The northern portion of Flammarion Sea to the east of Huggins Bay was dark gray, the other shadings appearing greenish gray. No mention is made in the original notes of any trace of the streaks from Trouvelot Bay or Huggins Bay, which last was judged to be on the polar diameter of the disk at $11^{h.} 56^{m.}$, G.M.T. It was not possible to decide whether any southern snow could be seen or not. The northern snow was of large dimensions, but it was very difficult to make out its true form.

The instrument used was the 8 inch reflector, with an achromatic eyepiece magnifying 220 diameters.

* Consisting chiefly of variations in the tone of the shadings, and irregularities of their outlines.

No. 23. Longitude=250°. 1879, Oct. 5. $15^{h.}\ 45^{m.}$ to $16^{h.}\ 10^{m}$ G.M.T. Hooke and Maraldi Seas are shown imperfectly separated by the northern portion of Burchardt Land. Huggins Bay is not distinguishable as a projection of Maraldi Sea, though the eastern termination of that sea in a fine point is very distinct. A dark patch is shown in Hooke Sea to the south of Gruithuisen Bay. Dreyer Island (Green) and Lockyer Land are plainly visible, together with the intervening Zöllner Sea, and Flammarion Sea, adjoining Hind Peninsula. The Kaiser Sea and a part of Dawes Ocean are shown just within the eastern limb and the faint offshoot of the former, known as Main Sea, is very distinct, seeming to be prolonged, with one interruption, nearly to the arctic circle. Gruithuisen Bay sends off a faint streak to the N.W., as in so many later sketches. The northern snow was small and faint, and none appears to have been seen in the neighbourhood of the S. Pole. A region of great brightness lay to the east of the Kaiser Sea.

The 8-inch reflector was employed for these observations, seemingly with an achromatic eyepiece magnifying 380 diameters.

No. 24. Longitude=309°. 1879, Dec. 10. $10^{h.}\ 31^{m.}$ to $11^{h.}\ 5^{m.}$ G.M.T. This drawing, made with a power of 408 diameters on the 12-inch reflector, shows the Kaiser Sea with its southern extremity in almost the most favourable position for close scrutiny. The atmospheric conditions were most propitious, as is imperfectly indicated by the observation of Nasmyth Inlet in such close proximity to the northern limb. Calculating from its known width and latitude, the apparent breadth at the time of drawing it must have been considerably less than $0{\cdot}2''$ (two tenths of a second of arc). Notwithstanding its extreme attenuation, it was so clearly seen that I have no hesitation in saying that if any of the canals depicted in Professor Schiaparelli's maps of this region had existed *as visible objects* on Dec. 10, I must have seen them. Nothing of the kind was seen, however, on *this* night. Hirst Island was utterly invisible,* and immediately to the north of its place was a large pear-shaped shading, similar to that seen in 1871 and 1873 by Mr. Knobel and by the writer to occupy the same position. Banks Cape appears prolonged into an isthmus, dividing the Kaiser Sea from Herschel II. Strait. Possibly this isthmus is simply formed by a union of Hirst Island with Banks Cape, a state of things which seems to have been the rule in 1862 and 1864, according to the evidence of Professor Kaiser. Zöllner Sea, Lambert Sea, and Lockyer Land are very conspicuous. Cassini Land and Dreyer Island form a single white or light-coloured patch, corroborating the evidence afforded by the elongation of Banks Cape as to the prevalence of clouds in this region. Phillips Island is visible, as well as a trace of Kunowski Land. Between Nasmyth Inlet and the northern limb there was a brilliant white stripe. At the southern edge of Beer Continent there was a narrow white line following the sinuosities of the outline from a point some distance to the W. of Banks Cape, at least as far as Dawes Forked Bay. The two

* As a separate marking.

points of Dawes Forked Bay were seen as one ill-defined point, which is not wonderful, considering that they were some 50° distant from the central meridian. Near the eastern limb a trace of Phillips Island was clearly seen, and Burchardt Land could be faintly descried close to the opposite point of the disk. The amount of detail visible was far too great to be transferred with accuracy to a drawing within the time available for the purpose; especially as regards the junction of the Kaiser Sea and Ocean of Dawes, where the unavoidable omissions have been most numerous owing to the constant slight flickering of the image, which prevented the eye from dwelling on minute points of detail sufficiently long to be perfectly assured that their true forms had been made out.

Areographic Positions of the Markings as deduced from the Drawings.

A full discussion of the results obtained naturally includes the determination of the places of the markings observed, in other words, of their areographic latitudes and longitudes. This has in the present instance been accomplished by the method first made use of, so far as I am aware, by the late Professor Kaiser of Leyden, details of which are given by him in the third volume of the Annals of the Leyden Observatory; pp. 50–51. Briefly, his process was firstly to compute the position of the axis of Mars, and of the assumed first meridian, for certain dates included within the period embraced by the observations; then to construct from these data diagrams, representing on the orthographic projection the circles of longitude and latitude on the same scale as the drawings, but on transparent paper; finally, placing these diagrams successively upon each drawing in such a position that the polar diameter of the diagrams passed through the centre of the polar snow spot, and the outlines were accurately superposed, it was easy to read off on the diagram the angular distance of any spot from the central meridian and from the equator. Knowing by calculation the areographic longitude of the centre of Mars' disk at the time of observation, it was a very simple matter to ascertain that of any spot on the drawing. This process was repeated with the second diagram, and the true place of the spot found by interpolation for the date of observation.

In the case of the drawings now laid before the Royal Dublin Society hardly any calculation was required, thanks to the Ephemeris of Mr. Marth, already referred to, which furnished all the numerical data needed. Two diagrams were constructed as above described; the first answering to 1879, Oct. 14, the second corresponding to 1879, Dec. 8, and 1880, Jan. 2. Owing to the distribution of the drawings in time, it was found safe to use these two diagrams for the whole term of the observations, as the corrections for change of the planet's position never exceeded 5° in latitude for any drawing. The method of using the diagrams was the same as Prof. Kaiser's, but the longitude of the centre of the disk was interpolated from Marth's Ephemeris. Though the results can scarcely attain to the accuracy reached by Professor Kaiser, yet as they furnish a numerical measure of the

correctness of the accompanying drawings, and may aid in deciding some points hitherto left in obscurity, I venture to give them in detail, arranging the points measured in order of longitude.

In the following small tables, column 1 gives the ordinal number of the sketch on which the measures have been made; column 2, the separate results for longitude; column 3, the separate results for the latitude of the spot named at the head of each table. At the foot of each column of results is given the mean deduced value of each element, usually the simple arithmetical mean. In some cases, where the sketches employed show the markings measured at very different parts of the disk, it was judged advisable to give different weights to the several results, the greatest weight being given to a determination made near the central meridian of the disk. South latitudes are considered positive.

Dawes Forked Bay.

1	2°	−12°
2	6	− 5
3	6	−15
4	6	0
24	354	+ 5
Means, .	3	− 5

Beer Bay.

1	25°	− 3°
2	21	+10
3	25	− 3
4	16	− 3
5	17	− 0
6	18	(−25) omitted in mean.
Means, .	20	0

'Lake' at north end of 'Canal' proceeding from Beer Bay.

1	27°	−30°
2	30	−40
Means, .	28	−35

North-west angle of Christie Bay.

1	57°	0°
3	68	18 ?
5	49	5
6	68	5
7	63	0
10	(79) ? omitted in mean.	8 (near limb.)
Means, .	61	6

Lake Schiaparelli.

6	78°	19°
7	74	24
10	87	25
11	77	18
Means, .	79	22

Terby Sea.

6	95°	22°
7	92	24
10	90	20
11	93	28
Means, .	93	24

Spot possibly identical with the Terby Sea; drawn on December 24.

8	95°	20°
9	91	24
Means, .	92	22

Bessel Lake.

11	108°	23°

Dusky speck near the place of Bessel Lake. Query, identity?

10	116°	13°

(Bay of Funchal.)

7	115°	33°
10	118	36
11	113	36
Means, .	115	35

Western bend of the 'Canal' proceeding from Trouvelot Bay. Rather faint, especially with the 6-inch.

12	140°	−10°
13	174	− 8
14	133	0
20	156	5
Means, .	151	− 3

Trouvelot Bay.

12	175°	20°
13	184	30
14	158	20
15	151	20
16	165	30
17	180	30
18	170	20
19	165	20
20	176	20
Means, .	169	23

Noble Cape.

16	170°	32°
17	190	28
18	187	28
19	175	26
20	190	30
Means, .	182	29

Oudemann Sea (centre).

16	190°	− 35°
17	150	− 25
18	190	− 40
19	190	− 40
21	200	− 30
Means, .	184	− 34

North end of 'Canal' from Huggins Bay.

16	190°	− 10°
18	200	− 20
19	200	− 25
21	180	− 14
Means, .	193	− 23

Western end of Hooke Sea.

16	235°	35°
17	236	31
18	232	26
19	255	34
21	228	33
22	216	35
Means, .	234	33

Huggins Bay.

15	236°	0°	very near the limb.
16	250	− 3	
17	260	− 5	
18	230	6	
19	240	13	
20	256	10	
21	238	11	
22	230	5	
23	230	18	
Means, .	241	6	

North end of Burchardt Land.

18	245°	8°
19	–	8
21	254	7
22	246	10
23	245	10
Means, .	248	9

Middle of 'Canal' running N.W. from the neighbourhood of Gruithuisen Bay.

18	260°	− 20°
19	270	− 15
21	270	− 20
22	270	− 15
23	235	− 20
Means, .	260	− 18

Gruithuisen Bay.

18	267°	4°
22	280	0
23	258	0
Means, .	268	1

Junction of Kaiser Sea with Nasmyth Inlet.

24	285°	− 40°

East end of Hind Peninsula.

23	288°	+ 3°
24	293	− 8
Means, .	295	− 3

East end of Dreyer Island.

23	300°	23°
24	289	25
Means, .	295	24

Middle of Kaiser Sea.

23	295°	5°	near limb.
24	302	− 10	double weights, being central.
Means, .	298	− 5	

Centre of dark pear-shaped area of Dawes Ocean.

24	300°	5°

Middle of Nasmyth Inlet.

24	300°	− 45°

Lockyer Land (centre).

4	–	45°
23	290° ($\frac{1}{2}$ wt.)	44
24	304	54
Means, .	301	48

Banks Cape ; junction with Beer Continent.

24	314°	14°

Phillips Island, W. end.

24	344°	12°

Phillips Island, E. end.

2	6°	17°
3	353	5
4	8	25
Means, .	2	16

∴ Centre of Phillips Island.

353°	14

Mean Places.

Marking.	Longitude.	Latitude.	No. of determinations.
Dawes Forked Bay, ...	3°	– 5°	5
Beer Bay, ...	20	0	6
Lake north of Beer Bay, . . .	28	– 35	2
North-west angle of Christie Bay, . .	61	6	6
Lake Schiaparelli, ...	79	22	4
Terby Sea, ...	93	24	4
Terby Sea ? December 24, . . .	93	22	2
Bessel Lake, ...	108	23	1
Dusky speck near Bessel Lake, . .	116	13	1
(Bay of Funchal), ...	115	35	3
West bend of Canal from Trouvelot Bay, .	151	– 3	4
Trouvelot Bay, ...	169	23	9
Noble Cape, ...	182	29	5
Centre of Oudemann Sea, . . .	184	– 34	5
North end of Canal from Huggins Bay, .	193	– 23	4
West end of Hooke Sea, . . .	234	33	6
Huggins Bay, ...	241	6	9
North end of Burchardt Land, . .	248	9	4, 5
Middle of Canal from Gruithuisen Bay, .	260	– 18	5
Gruithuisen Bay, ...	268	1	3
Junction of Kaiser Sea and Nasmyth Inlet, .	285	– 40	1
East end of Hind Peninsula, . . .	295	– 3	2
East end of Dreyer Island, . . .	295	24	2
Middle of Kaiser Sea, ...	298	– 5	2
Dark patch in Dawes Ocean (centre), . .	300	5	1
Middle of Nasmyth Inlet, . . .	300	– 45	1
Lockyer Land (centre), . . .	301	48	2, 3
Banks Cape (north end), . . .	314	14	1
West end of Phillips Island, . . .	344	12	1
East do. do., . . .	2	16	3
Centre* do., . . .	353	14	(1)

The preceding results are compared with those obtained by Beer and Mädler, by Kaiser, by Green, and by Schiaparelli, where there seems to be no reasonable doubt that the same points have been measured by the several observers named, and by myself, in the annexed Table. In the first column are given the names of the markings, usually taken from Mr. Green's map ;† and in the remaining columns are entered the differences obtained, which are considered positive when the earlier determination is numerically the largest. For brevity, the following initials are employed in the headings of the columns of differences :—

* Concluded from positions of the extremities.

† Exceptions : Beer Bay (Proctor), and Funchal Bay (*vide* page 156 of this memoir).

B. M.	.	Beer and Mädler.
K.	.	Kaiser.
S.	.	Schiaparelli.
G.	.	Green.
D.	.	Dublin, 1879–80, by Messrs. Dreyer and Burton.

Marking.	B. M.—D. Long.	Lat.	K.—D. Long.	Lat.	S.—D. Long.	Lat.	G.—D. Long.	Lat.
Dawes Forked Bay,	—3°	—12°	—3°	1°	—3°	0°	—11°	5°
Beer Bay,	—7	8	—	—	—7	4	—15	5
Lake north of Beer Bay,	—	—	—	—	—	—	—	—
North-west angle of Christie Bay,	—	—	4	13	6	—4	2	—9
Schiaparelli Lake,	—	—	—	—	15	2	—13	6
Terby Sea,	—2	4	—4	4	—3	+1	— 9	2
Bessel Lake,	—	—	—	—	—1	—4	—10	—15
Funchal Bay,	—	—	—	—	—5	—3	—17	— 9
West angle of Canal from Trouvelot Bay,	—	—	—	—	(±2)	(±1)	—	—
Trouvelot Bay,	14	0	(11)	(9)	5	—5	— 1	— 3
Noble Cape,	—	—	—	—	—	—	3	— 4
Oudemann Sea,	—	—	—	—	—	—	4	— 6
West end of Canal from Huggins Bay,	—	—	(10)	(0)	12	(7)	—	—
Hooke Sea, west end,	—	—	—	—	— 8	— 4	(6)	(7)
Huggins Bay,	—	—	—	—	—16	6	—16	2
Burchardt Land, north end,	—	—	(4)	(2)	2	4	(—3)	(1)
Middle of Canal from Gruithuisen Bay,	—	—	—	—	8	— 2	—	—
Kaiser Sea and Nasmyth Inlet,	—	—	—	—	(3)	(0)	(3)	(2)
East end of Hind Peninsula,	—	—	(5)	(11)	—	—	(—15)	(10)
East end of Dreyer Island,	—	—	—	—	(—11)	(—7)	(—18)	(—2)
Middle of Kaiser Sea,	—11	6	—4	—21	— 5	—12	—10	0
Dark patch in Dawes Ocean,	—	—	15	10	—	—	—	—
Middle of Nasmyth Inlet,	—	—	—	—	(—10)	(0)	10	5
Lockyer Land (middle),	—	—	—	—	— 7	— 2	— 1	2
Banks Cape,	12	5	7	3	4	— 4	— 2	—4
Centre Phillips Island,	—	—	—	—	7	6	— 8	1

Nomenclature.—In the preceding lists the nomenclature employed by Mr. N. E. Green, in his paper published in the *Memoirs of the Royal Astronomical Society*, vol. 44, has been usually employed, as that which is, perhaps, best known to workers in the British Islands who have devoted themselves to observation of Mars; based as it is on the system of names introduced by Mr. Proctor some years since, and adopted in his published charts of the planet. But, perhaps, I may be permitted to express an earnest hope that some system of nomenclature may be introduced which is free from the objections inseparable from a system admitting of the employment of the names of living persons, and shall serve naturally and conveniently to distinguish the several markings by designations as far as possible of a mnemonic character, recalling the characteristic features of the markings to which they are attached.

NOTE ADDED IN THE PRESS.

It may be well to bear in mind the real minuteness of the differences recorded in the Tables given in the text. At the time of Mars' nearest approach to the earth last autumn, the apparent diameter of his disk was about 20″ (seconds of arc), and consequently one degree of a Martian great circle subtended to a terrestrial observer no more than $\frac{20}{115}''$, or little more than one-sixth of a second of arc, when at the centre of the disk.

The prevalence of the minus sign and the large amount of the differences in the last column of longitude under the heading G–D is due to the selection by Mr. Green of a first meridian 11° to the east of the point which seems to have been adopted by Mr. Marth in his Ephemeris before mentioned. In strictness, therefore, 11° ought to be added to Mr. Green's longitudes to eliminate this constant difference.

Similarly, the constant differences of longitude between the results obtained by Professor Schiaparelli from Professor Kaiser's and from his own observations, and those which I have deduced, amount respectively to—1° and to—3°.

General Survey of Results.

The accompanying chart,* the fundamental points of which have been laid down in accordance with the Table of Areographic co-ordinates given on page 166, includes the whole of the apparently permanent markings seen at Dunsink, and at Loughlinstown.

The details not included in the list of positions have been inserted by eye-estimation, and it was my aim throughout this part of the work, to distinguish what was accidental and temporary from that which was permanent. The principal aid available for making this discrimination has been the well-known and long established fact that the dark markings, as a rule, have always occupied sensibly the same positions on the globe of Mars whenever they were distinctly seen, and that in many instances of apparent change it has been found, by persevering scrutiny, that the alteration was due to the formation or removal of luminous veils, akin to terrestrial clouds, which concealed or disclosed to view the subjacent features of the planet's actual surface.

Consequently, I have been led to insert on the chart every dark shading seen, even if detected on one occasion only; and to ignore those light markings which do not find a place in all the drawings which include their positions. As the position of Mars' axis was very unfavourable in comparison to those taken up at the oppositions of 1871, 1873, and 1877, for scrutiny of either of the polar regions, and as the projection adopted for the chart is free from distortion as regards latitude, it has seemed unadvisable to construct special polar charts from the observations of 1879–80.

The Polar Snows.—On the whole the northern snow spot was far brighter and larger than the southern, notwithstanding that the northern pole was some distance from the limb within the averted hemisphere, and the southern the same distance within the visible hemisphere. Generally a few bright specks were all that could be seen of the southern snow, while the northern appeared to extend on Dec. 10 as far as the northern boundary of Nasmyth Inlet in N. latitude 45°. If concentric with the N. pole this frozen region must consequently have had a diameter of about

* Fig. 1, Plate VIII.

90 Martian degrees, or included within it some 3,000 miles of the meridian. On more than one occasion, when both snow spots were visible, it was evident that no diameter of the disk would bisect both, and the greater eccentricity of the southern appeared to be established by the more striking changes of magnitude which it underwent in comparison with the northern snow spot, together with the far greater fluctuations in the brilliancy of the former. The northern snow spot did not visibly alter its position on the limb, or its magnitude, to any considerable extent, and its invisibility on Nov. 18, for instance, is to be ascribed to the interposition of immense masses of cloud. On the date mentioned all markings near the northern limb appeared dim and very ill-defined. On Nov. 22 the clouds had partially cleared away, and the snow was distinctly, though faintly, seen. The presence of cloud is also probably traceable in the appearance of Banks Cape and Hirst Island as a single marking, in No. 24 (Dec. 10). Another instance is afforded by No. 22 (Nov. 10), where the western extremity of Hooke Sea is cut off from the remainder by a bright narrow space not shown in any other of the drawings.

It is singular that in many cases the clouds seem to be indistinguishable from the brighter parts of the disk, which are usually of an orange colour, inclining to red, by any perceptible difference of tint. Other observers who have inferred the existence of Martian clouds, appear, like myself, rather to have inferred the presence of such obstacles to vision from the disappearance or enfeeblement of well-known markings under otherwise favourable conditions for their visibility, than from any peculiarity of tint or reflective power possessed by the clouds themselves. These veils have been seen by Lockyer to change their position as if borne by winds (23rd September, 1862). There can, therefore, be little doubt of their analogy at least to terrestrial clouds, or, more probably, to ground mists. In connexion with the preceding remarks on the colour of the clouds of Mars, it may be mentioned that on Jan. 5, 1880, the southern snow region was much fainter and less definite than the northern, and appeared yellowish, while the northern was white. This observation seems to indicate that the southern snow had been covered, or possibly replaced by tinted clouds, as this region had been exposed continuously for several months to the sun's rays.

The presence of mist or hoar-frost for some time after sunrise on Mars seems to be indicated by the frequently observed dimness and indefiniteness, or even invisibility of the markings near the eastern limb, while they could often be followed to within less than a second of arc from the western limb; *e.g.* Jan. 5, when Christie Bay was indistinct, though it was far within the eastern limb. But on many other occasions, the reverse held good, as on Oct. 24, when Christie Bay and Terby Sea were well seen near to the eastern limb, while Beer Bay and the regions west of it are lost in a diffused whitishness which extended to the west limb. So on Nov. 18 and Nov. 22. An inspection of the Plates VI. and VII. will readily furnish other instances of both modes of behaviour. This whitishness may be considered as undoubtedly

connected with the comparatively feeble power of the sun's rays at oblique incidences. It seems to have been more obvious in 1879–80 than in 1877, probably because the planet was more distant from the sun at the later epoch. We may connect this with the frequent apparition of brilliant menisci bordering the limb, observed in 1871–73 when Mars was not far from aphelion.

The 'Canals.'—This designation has been applied by Professor Schiaparelli to the narrow dusky streaks which seem to connect the so-called 'Seas,' and traverse most of the Martian Continents, often for distances equalling a thousand terrestrial miles, and that without any notable variation in breadth. Most of these remarkable objects were discovered by Signor Schiaparelli in 1877–78, with the $8\frac{3}{4}$-inch Merz achromatic of the Royal Observatory of Brera, near Milan, and appear to have been in part independently detected by myself, in 1879. These re-discoveries were chiefly made in the region lying between the meridians of 350° and 60°, and the parallels of 40° N., and 10° S., and are confirmed by one of Mr. Dreyer's sketches (No. 1 of this series). The streak connected with Dawes Forked Bay, is probably identical with Dawes Strait, which has been known to observers for upwards of fifteen years. That connected with Beer Bay according to several sketches, is the Indus of Schiaparelli, and the streak from Christie Bay to N.N.W., though not seen by him in 1877, has been independently seen at Brera in 1879.

The longest 'Canals' observed by me connect Trouvelot, Huggins, and Gruithuisen Bays with Oudemann Sea and its neighbourhood, and may be identical with the Canals of the Giants, of the Cyclops, and the River of Lethe, shown on the Brera maps. Considering the difficulty of the objects, the discordances in the forms given to these streaks by different observers, hardly afford grounds for surprise. Their character appeared to me to be always the same, and when best seen with powers up to 514 on the 12-inch reflector, their appearance was that of long, undulating, sharply bounded stripes of a light greenish gray hue. Nothing* was seen which indicated their real nature to be rows of separate patches generally confused together to form apparent streaks, as they invariably seemed to be perfectly continuous. The edges were once or twice seen not to be smooth, but minutely undulated or serrated, according to very distinct recollection of some good views obtained with high powers.

I have little doubt that these 'canals' are identical in nature with the 'seas,' though the connexion between them is occasionally singularly complex (*vide* note on Beer Bay, January 5), and difficult to define accurately. Chart 1, Pl. VII., merely indicates the position and direction of each 'canal,' without any special attempt to reproduce its aspect, which must be learnt from the drawings alone.

A comparison of Mr. Dawes' drawings of 1864, and of Mr. Proctor's chart, chiefly deduced from them, with the Brera maps and with the sketches illustrating

* *Vide* the remarks upon drawings Nos. 5, 20 and 21 *supra.*

this notice, reveals the fact that Huggins Inlet* has by no means ceased to exist, as it is plainly visible in both the latter series of drawings, Schiaparelli having designated it the Canal of the Cyclops. See also Nos. 15, 16, 18, 19, 20, 21, of the present series. The streak running N.W. from Christie Bay is beautifully shown in Dawes' drawings. Great caution is therefore necessary in asserting that any 'canal' is a recent formation, considering our present almost total ignorance of the forces and other conditions which are able to efface for years together markings at other times so distinctly visible that a tolerably extensive acquaintance with earlier records alone saves the observer from fancying himself a discoverer of new details.

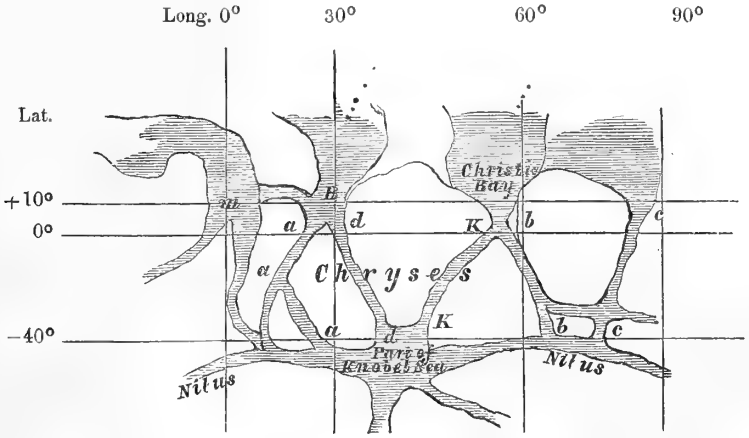
There is little risk of error in the assertion, that as instruments of high quality increase in number, and as observers become more skilled, many of the discrepancies between their results will disappear, or will be *distinctly* referable to changes in the planet itself.

From this point of view we must regard all the charts of Mars hitherto compiled, as in great part provisional, and many years will probably elapse before an authoritative map of the entire surface of the planet can be prepared, even supposing that no real changes are in progress there.

If the notes and drawings now laid before the Royal Dublin Society, help in any degree toward the attainment of this object, their authors† will be well repaid for their trouble.

APPENDIX ADDED IN PRESS.

Sketch map of the Region of Mars included between the 350th and 60th degrees of Longitude and the parallels of 50° north and 20° south Latitude, with remarks by Dr. J. V. Schiaparelli, Director of the Royal Observatory of Brera, near Milan.



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* According to Schiaparelli, Huggins Inlet can scarcely be identical with the Gulf of the Cyclops. But see remarks on page 159 ; also Dr. Terby's comparative Table of Nomenclatures. *Bulletins de l'Academie Royale de Belgique*, XLVIII., 12, pp. 6–15, for numerous identifications.

† Mr. Dreyer's responsibilities in connexion with the preceding paper extend only to the drawings and original notes on the same, which he has kindly contributed to it at my request.

By the kind permission of Dr. Schiaparelli, I am able to give this Map, and I venture to think that no better commentary on it can be found than Dr. Schiaparelli's own words, a literal translation of which is here given. *Vide* also his memoir 'On Observations of Mars,' published in the *Atti della Reale Accademia dei Lincei*, 1877–8.

"All the details contained in that chart (*loc. cit.*) have been fully confirmed by my observations of 1879, which (year) has been much more favourable here than that of 1877. There is no exception, save for the surroundings of the region named Aurea Cherso [*Browning and Copernicus Land* (Green)], which I have not been able to study as conveniently in 1879, and in which, perhaps, some change has taken place. Other more or less considerable changes have been detected in other regions of the planet, probably in consequence of altered meteorological conditions. Thus the Nile beneath Chryses [a part of *Mädler Continent* (Green)] was in 1879 interrupted by a large 'lake,' which is, probably, the southern part of Tycho Sea [*Knobel Sea* (Green)]. From that lake issue eight branches or 'canals,' as shown in the annexed sketch (*vide* Map). Not having as yet computed the positions, the lower portion of the sketch shows the objects violently foreshortened, nearly as I have seen them. The lines (canals) *aa*, *bb*, *cc*, are much stronger than the others. *aa* is the Indus [? *Dawes Strait of Proctor*, Terby], *bb* the Ganges, *cc* the Chrysorrhoas of my chart. At *m* is the *forked bay of Dawes*. A part of all that is recognisable in your drawing No. 3. The 'canal' *dd* (Hydaspes, *Dawes Strait*, according to Schiaparelli) was very conspicuous in 1864, and I find it in all Dawes' drawings. In 1877 I could only see its mouth. Lastly, the 'canal' *kk* is probably the same which occurs in your sketch of October 24th (No. 6), no trace of which was visible in 1877.* In November and December it was broad and very distinct, almost as much so as the Ganges. The luminous band which you have marked in the same drawing as traversing the Sinus Auroræ (*Delarue Ocean*) is indeed the same transitory phenomenon which I saw on September 26th, 1877." The letter above quoted bears date Jan. 17, 1880.

On March 22, 1880, Dr. Schiaparelli writes as follows:—"If you desire to introduce my sketch of the regions below, *i.e.*, north of the Erythræan Sea (*Strait of Herschel II.*), into your memoir, I shall be honoured, only I beg you to give notice that the respective positions are laid down from eye estimations, and they will undergo corrections when I shall have finished the computation of micrometric measurements for the purpose of compiling a regular chart."

There will, however, be no difficulty in comparing this map with that forming Fig. 1, Plate VIII., by making the required alterations mentally.

* It appears in Dawes' drawings of 1864.

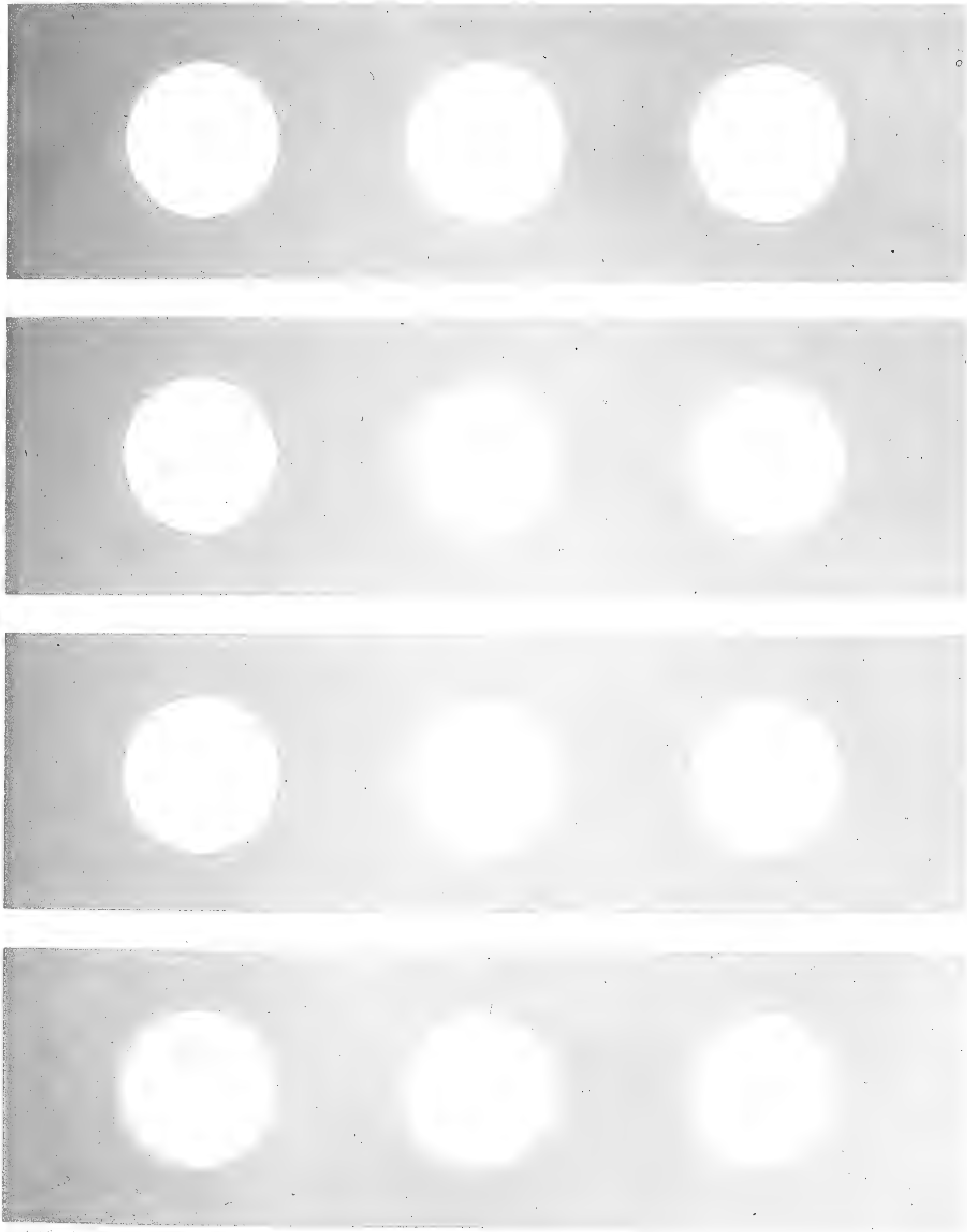
TABLE of LONGITUDES of CENTRAL MERIDIAN of MARS' DISK corresponding to each of the Drawings.

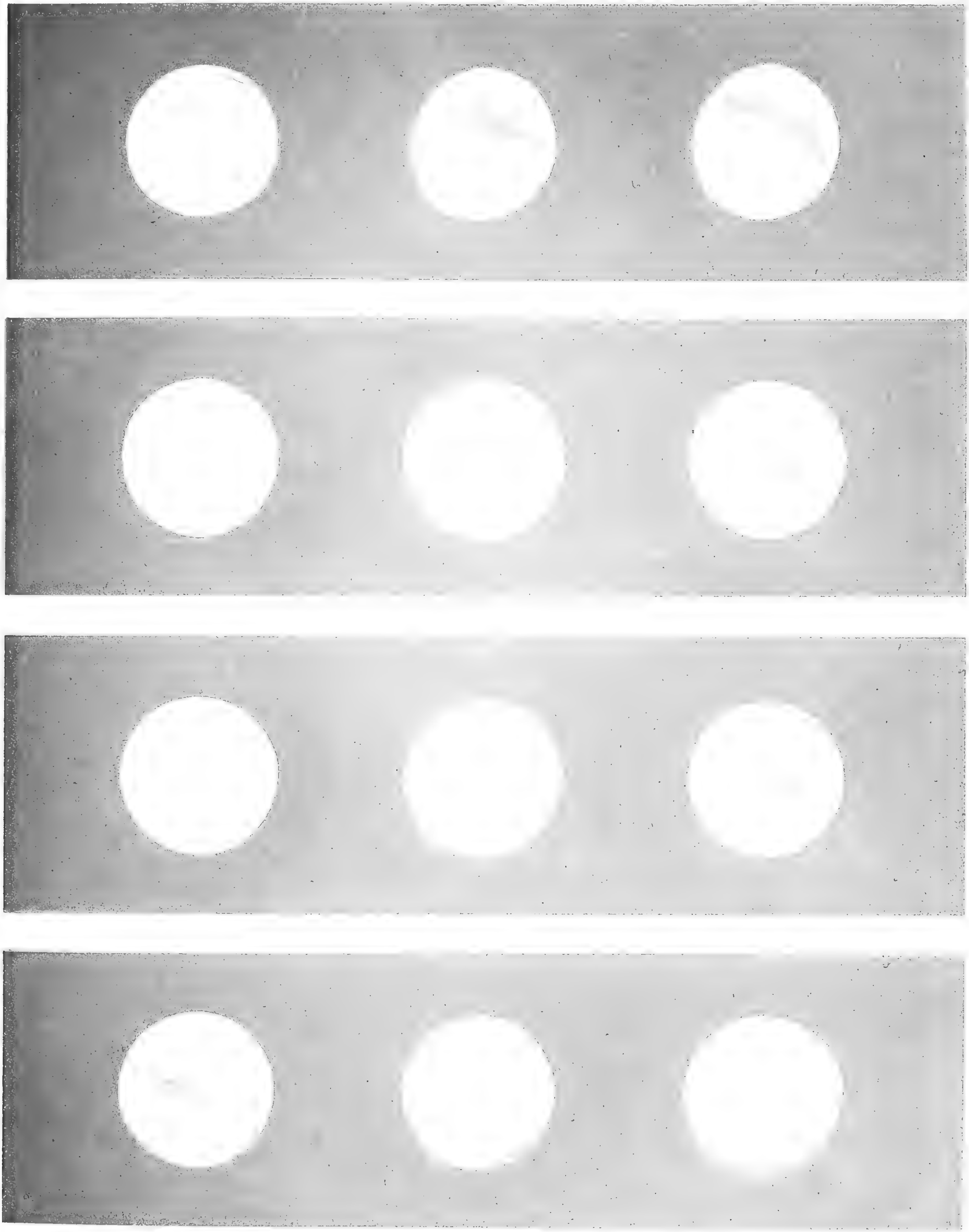
(Plates VI. and VII.)

No. of drawing.	Longitude of centre.	No. of drawing.	Longitude of centre.	No. of drawing.	Longitude of centre
1	16°·7 (at end.)	9	113°	17	211°
2	26	10	114	18	212
3	28	11	117	19	215
4	36	12	142	20	216
5	47	13	144	21	220
6	48	14	153	22	233
7	93	15	181	23	250
8	103	16	190	24	309

ERRATA ET CORRIGENDA.

Page 158, lines 2 and 18, .	*For* 270 *read* 241.
„ 159, line 11, . .	*For* 400 *read* 241.
„ 159, line 21 (end), .	*Dele* comma.
„ 161, line 8, . .	*For* southwards *read* northwards.
„ 164, . . .	The longitude of the suspected Terby Sea should be 93°.
„ 170, line 35, . .	*For* VII. *read* VIII.
„ 171, line 1 (Appendix), .	*For* 60th *read* 90th.
Plate VII., Fig. 24, . .	The central part of Beer Continent should be *uniformly* shaded.
„ VIII., Fig. 1, . .	*Dele* the dusky speck S.E. of Schiaparelli Lake.
„ VIII., Fig. 2, . .	*For* Dreyer Sound *read* Dreyer Island.





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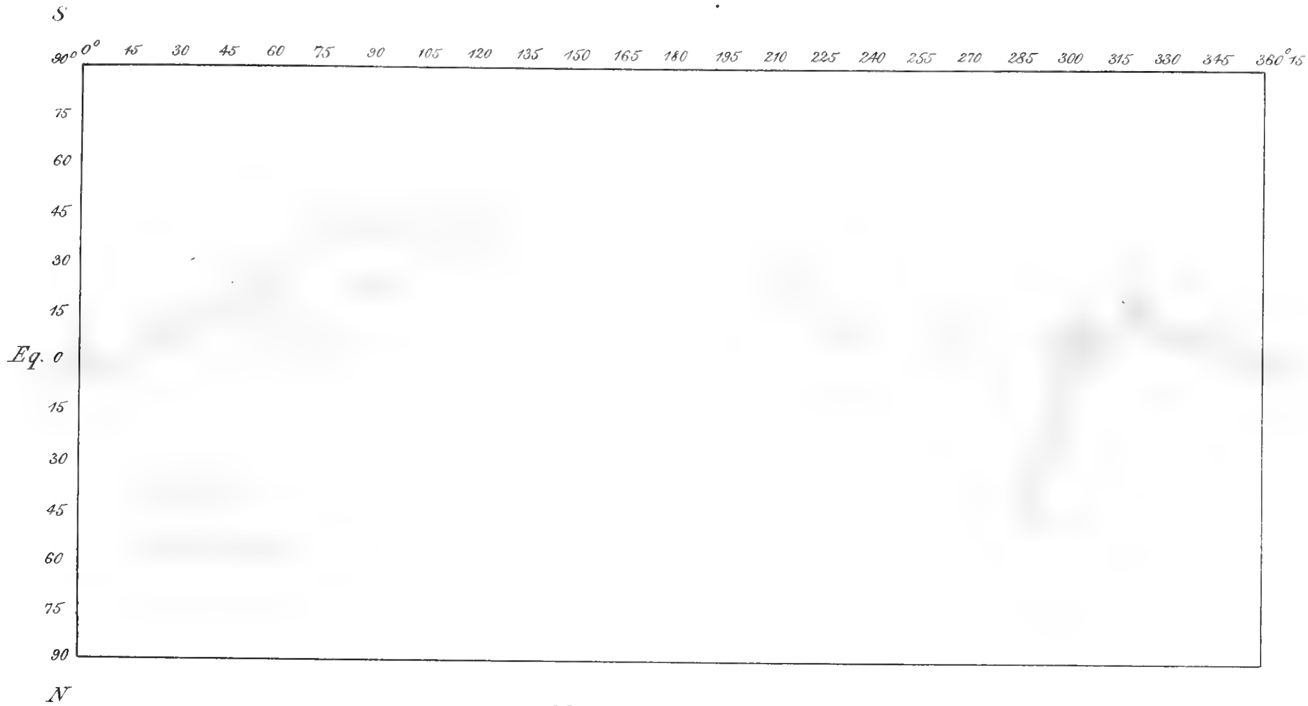
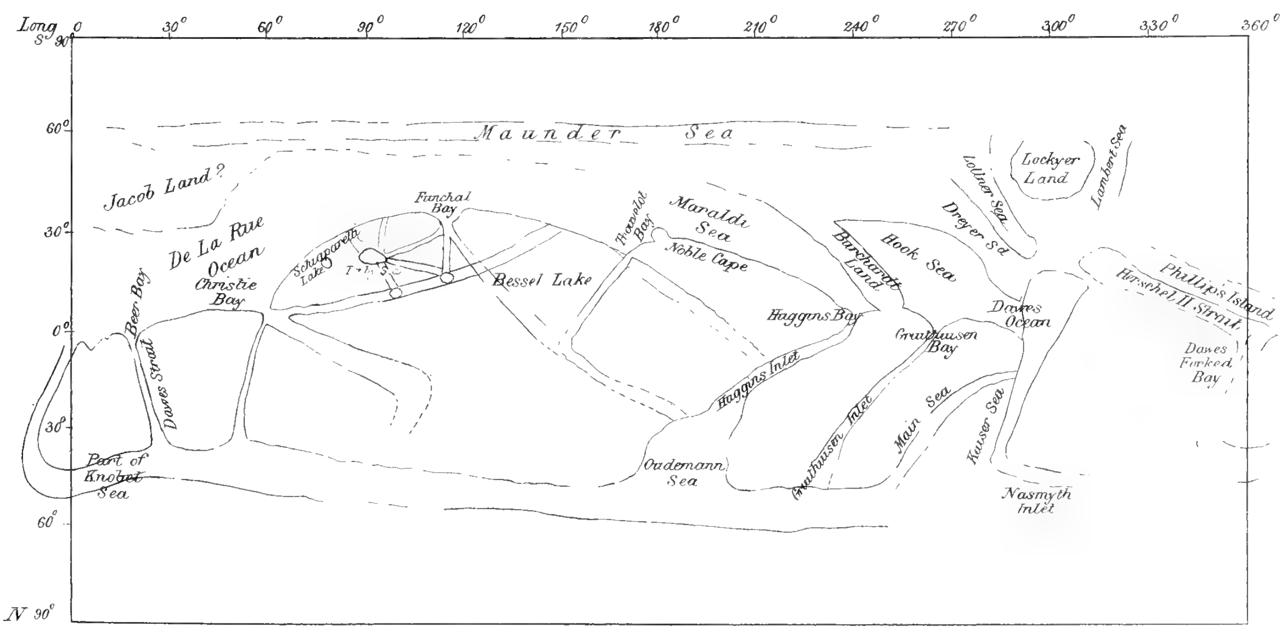
1



MARS, 1879-80.

This Chart is compiled from the Drawings by Messrs. DREYER and BURTON, given in Plates VI. & VII.

2.



MARS 1879-80.

Supplementary skeleton Chart, showing the nomenclature adopted in the Text.

TRANSACTIONS (NEW SERIES).
VOLUME I.

(Already Published.)

VOLUME II.

[NOVEMBER, 1880.]

THE SCIENTIFIC TRANSACTIONS OF THE ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XIII.—*On the Possibility of originating Wave Disturbances in the Ether by means of Electric Forces.* PART 2. BY GEO. FRANCIS FITZGERALD, M.A., F.T.C.D. [Read 19th May, 1880.]

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1880.

XIII.—ON THE POSSIBILITY OF ORIGINATING WAVE DISTURBANCES IN THE ETHER BY MEANS OF ELECTRIC FORCES. Part 2.

By GEO. FRANCIS FITZGERALD, M.A., F.T.C.D.

[Read 19th May, 1880.]

In a former paper, read before the Royal Dublin Society in February last,* upon the present subject, I showed that if the theories of action at a distance and Clerk Maxwell's of action through a medium lead to the same results in all cases, then there can be no production of waves propagated like light by means of such electrostatic or electrodynamic systems. I did not then point out where Clerk Maxwell practically assumes that this is the case, but he evidently does so when he assumes that the electrokinetic energy of a system of conductors carrying currents is a function of the present currents and their configuration only. By assuming this he has excluded the possibility of wave production, for in the case of wave production part of the energy of the system is in the medium, and what part is so, depends on the past as well as on the present configurations and currents.

There seems a very great difficulty in determining what is the actual distribution of displacement currents in the neighbourhood of a changing current in a conductor. We cannot assume them to be simply due to the variations of current in the conductor for such displacement currents immediately re-act on one another. We cannot even assume that they are initially the same as if they were directly and simply produced by the current in the conductor, for then this initial state would be a discontinuous one. The distribution at the limits of space, as well as time, are just as difficult to determine.

It is, however, possible to assume a distribution of electromagnetic potential in the neighbourhood of a conductor such that its components satisfy Maxwell's equation

$$\Delta^2 V + K\mu \frac{d^2 V}{dt^2} = 0$$

and yet such that it shall not represent a wave propagation such as light, but rather the state of vibration in an organ pipe where there are fixed nodes.

If we assume that V can be expanded in sines or cosines with regard to the time so that we may write

$$V = \Sigma V_n \begin{matrix}\sin\\ \cos\end{matrix} (nt)$$

where V_n is a function of x, y, z without t, then if we determine V_n suitably for a

* Vide Transactions Royal Dublin Society, Vol. 1, Part 10.

simple periodic $V = V_n \cos nt$, we see that the periods of maximum and minimum occur simultaneously everywhere so that it need not be of the nature of a wave propagation like light.

Now if $r = \sqrt{\overline{x-\alpha}^2 + \overline{y-\beta}^2 + \overline{z-\gamma}^2}$ then $V_n = \dfrac{\frac{\sin}{\cos}\left(\sqrt{K\mu}\,nr\right)}{r}$ satisfies the equation

$$\Delta^2 V_n = n^2 K\mu V_n$$

and we may get a more general form for V_n by taking it

$$V_n = \iiint f(\alpha\beta\gamma)\,\frac{\frac{\sin}{\cos}\left(\sqrt{K\mu}\,nr\right)}{r}\,d\alpha d\beta d\gamma$$

and we can make it have given limiting values by determining $f(\alpha\,\beta\,\gamma)$ rightly. This value of V_n vanishes for $r = \infty$.

We thus see that as

$$\frac{d^2V}{dt^2} = -\Sigma V_n n^2 \frac{\sin}{\cos}(nt)$$

and

$$\Delta^2 V = -K\mu\,\Sigma V_n n^2, \frac{\sin}{\cos}(nt)$$

we get that V satisfies the given equation $\Delta^2 V + K\mu \dfrac{d^2V}{dt^2} = 0$.

We thus see, generally, that if V contain a part depending on the time, and a part independent of it then it must be of the form just determined, in order to satisfy this equation.

We have then that V satisfies the given equation if it is expressible thus :—

$$V = \Sigma \iiint f(\alpha\beta\gamma)\,\frac{\frac{\sin}{\cos}\left(\sqrt{K\mu}\,nr\right)}{r}\,\frac{\sin}{\cos}(nt)\,d\alpha d\beta d\gamma.$$

This, of course, *may* represent a wave propagation, but a simply periodic variation of V in one curve in space would produce simultaneous maxima and minima values throughout space, and so would not originate wave disturbances at all.

There is another method by which we may arrive at this same distribution of displacement currents near a varying current.

Assume an initial distribution of currents (U) in conductors only, and calculate the electromagnetic potential at each point due to them, and then in terms of the initial acceleration of current ($\ddot{U}$) calculate the initial displacement current (u) throughout space. We may not assume this to be the total initial displacement current, for we must go on and calculate the acceleration ($\ddot{u}$) of this, and find the resultant displacement currents and so on. Then by summing up the resultant infinite number of these partial initial currents, we may assume that the resultant is the actual initial current at each point.

As we may deal with each element of current separately, I shall confine myself

to a current in the direction of x, and then the only component of the electromagnetic potential at each point is F and

$$F_0 = \mu \cdot \frac{U}{R}$$

(I distinguish the points at which F exists by the suffix). Where μ is the magnetic inductive capacity of the medium, and R is the distance of the point $_0$ from the current. The current at $_0$ produced by the acceleration of U is

$$u_0 = -\frac{K}{4\pi}\ddot{F} = -\frac{K\mu}{4\pi} \cdot \frac{\overset{2}{U}}{R} \text{ writing } \overset{2}{U} \text{ for } \ddot{U}.$$

Hence the vector potential at $_1$ due to this is

$$F_1 = -\frac{K\mu}{4\pi}\overset{2}{U}\int\frac{dm_0}{r_{10}R}$$

Where dm_0 is the element of volume at $_0$, and r_{10} is the distance from $_0$ to $_1$. Similarly

$$F_2 = \left(\frac{K\mu}{4\pi}\right)^2 \overset{4}{U}\int\frac{dm_1}{r_{21}}\int\frac{dm_0}{r_{10}R}$$

and generally

$$F_n = (-1)^n\left(\frac{K\mu}{4\pi}\right)^n \overset{2n}{U}\int\frac{dm_{n-1}}{r_{n.n-1}} \cdots\cdots \int\frac{dm_0}{r_{10}R}$$

Hence, if we call

$$\rho_n = \frac{1}{(4\pi)^n}\int\frac{dm_{n-1}}{r_{n.n-1}} \cdots\cdots \int\frac{dm_0}{r_{10}R}$$

we may write

$$F_n = (-1)^n (K\mu)^n \overset{2n}{U}\rho_n$$

and the relation connecting ρ_n and ρ_{n-1} is

$$4\pi\,\rho_n = \int\frac{\rho_{n-1}dm_{n-1}}{r_{n.n-1}}.$$

Before going further with this I may call attention to this, that if U were a simply periodic function of the time $= a \cos mt$, we can see that the complete F

$$F = \Sigma_0^\infty F_n$$

would necessarily be of the form

$$\cos mt\ \Sigma(K\mu)^n m^{2n}\rho_n = V_m \cos mt$$

so that as F is to satisfy the equation

$$\Delta^2 F + K\mu \cdot \ddot{F} = 0$$

we can see that V_m must be as before

$$V_m = A_m \frac{\begin{smallmatrix}\sin\\ \cos\end{smallmatrix}(\sqrt{K\mu}\cdot mR)}{R}$$

for it can only be a function of R as is evident.

We may get this otherwise by proceeding to determine ρ_n from ρ_{n-1} for we know that $\rho_0 = \frac{1}{R}$. We may do this with facility by observing that as ρ_{n-1} is a function of the co-ordinates of the point $_{n-1}$ only we have

$$\Delta^2\rho_n = \rho_{n-1}$$

or as ρ_n and ρ_{n-1} are all functions of R only we have that this reduces to

$$\frac{d}{dR}\left(R^2\frac{d\rho_n}{dR}\right)+R^2\rho_{n-1}=0$$

or what is the same integrated

$$\rho_n=-\int\frac{dR}{R^2}\int R^2\rho_{n-1}dR$$

From this we obtain neglecting the constants introduced by integration which do not affect the form of the result

$$\rho_0=\frac{1}{R}\,,\ \rho_1=-\frac{R}{2}\,,\ \rho_2=\frac{R^3}{\underline{|4}}\ \ldots\ \rho_n=\frac{(-1)^n}{R}\,;\ \frac{R^{2n}}{\underline{|2n}}$$

so that we evidently have

$$F_n=\frac{(K\mu)^n}{R}\cdot\overset{2n}{U}\frac{R^{2n}}{\underline{|2n}}.$$

Now in order to sum the results we must, as before, split up U in its components by expanding it in a series of sines and cosines, as before, when we may evidently take

$$F_n=\Sigma A_m\frac{\cos mt}{R}\cdot(-1)^n(K\mu)^n\,m^{2n}\cdot\frac{R^{2n}}{\underline{|2n}}$$

so that $\quad F=\Sigma F_n$

$$\therefore F=\Sigma A\ .\cos mt\,.\frac{\cos m\sqrt{K\mu}R}{R}$$

which is of the same form as before, as we saw it ought to come out.

There are some obvious objections to the latter part of this enumeration, in which several of the terms are infinite if the space be infinite.

The only assumption I seem here to have made is that the initial disturbance is the sum of all the initial induced currents, and this seems the only natural and an almost necessary assumption.

As $\frac{1}{\sqrt{K\mu}}$ is the velocity of light, $\sqrt{K\mu}$ is very small, so that with currents varying at the rate they usually do $\cos m\sqrt{K\mu}R=1$ for any not very large value of R and F, and so has the same value as if there were no induced displacement currents at all.

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TRANSACTIONS (NEW SERIES).

VOLUME I.

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PART.

1.—On Great Telescopes of the Future. By HOWARD GRUBB F.R.A.S. (November, 1877.)

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6.—Notes on the Physical Appearance of the Planet Mars, as seen with the Three-foot Reflector at Parsonstown, during the Opposition of 1877. By JOHN L. E. DREYER, M.A. With Plates I. and II. (November, 1878.)

7.—On the Nature and Origin of the Beds of Chert in the Upper Carboniferous Limestone of Ireland. By Professor EDWARD HULL, M.A., F.R.S., Director of the Geological Survey of Ireland. And On the Chemical Composition of Chert and the Chemistry of the Process by which it is formed. By EDWARD T. HARDMAN, F.C.S. With Plate III. (November, 1878.)

8.—On the Superficial Tension of Fluids and its Possible Relation to Muscular Contractions. By G. F. FITZGERALD, M.A., F.T.C.D. (December, 1878.)

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10.—On the Possibility of Originating Wave Disturbances in the Ether by Means of Electric Forces. By GEO. FRAS. FITZGERALD, M.A., F.T.C.D. PART 1. (February, 1880.)

11.—On the Relations of the Carboniferous, Devonian, and Upper Silurian Rocks of the South of Ireland to those of North Devon. BY EDWARD HULL, M.A., LL.D., F.R.S., Director of the Geological Survey of Ireland, and Professor of Geology, Royal College of Science, Dublin. With Plates IV. and V., and Woodcuts. (May, 1880.)

12.—Physical Observations of Mars, 1879–80. BY C. E. BURTON, B.A., M.R.I.A., F.R.A.S. With Plates VI., VII., and VIII. (May, 1880.)

13.—On the Possibility of originating Wave Disturbances in the Ether by means of Electric Forces. PART 2. BY GEO. FRANCIS FITZGERALD, M.A., F.T.C.D. (November, 1880.)

VOLUME II.

1.—Observations of Nebulæ and Clusters of Stars, made with the Six-foot and Three-foot Reflectors at Birr Castle, from the year 1848 up to the year 1878. Nos. 1 & 2. By the RIGHT HON. THE EARL OF ROSSE, LL.D., D.C.L., F.R.S. With Plates I. to IV. (August, 1879.)

1.— Do. Do. Do. No. 3. With Plates V. and VI. (June, 1880.)

[April, 1881.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XIV.—*Explorations in the Bone Cave of Ballynamintra, near Cappagh, County Waterford.* By A. Leith Adams, M.B., LL.D., F.R.S., F.G.S. G. H. Kinahan, M.R.I.A. and R. J. Ussher. Plates IX. to XIV.

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1881.

XIV.—EXPLORATIONS IN THE BONE CAVE OF BALLYNAMINTRA, NEAR CAPPAGH, COUNTY WATERFORD. By A. Leith Adams, M.B., LL.D., F.R.S., F.G.S. G. H. Kinahan, M.R.I.A. and R. J. Ussher. Plates IX. to XIV.

[Read November 15th, 1880.]

CONTENTS.

I.—Preliminary Remarks by R. J Ussher.

That the Valley between Dungarvan Bay and the Blackwater was a resor t o the huge Mammalia that characterized the Post Pleiocene epoch has been repeatedly proved.

Smith, in his "Ancient and Present State of the County and City of Waterford," p. 81, states, "Some years ago we dug up, within a mile of Whitechurch, the rib of an elephant, it agreeing with the description of that animal in Dr. Moulins and Blair." Of this rib he gives a figure.

More than a century ago two very perfect pairs of reindeers' antlers, now in possession of John Quinlan, Esq., of Clonkerdin, are said to have been found in a bog at Ballyguiry, on the south side of the valley*.

About the year 1830, or earlier, the late Richard Ussher, when excavating ponds in the peat, east of Cappagh, found the bones and antlers of as many as sixteen Irish elks. Most of these remains are said to have been found congregated near one particular spot.

A Mr. Stack, a farmer living at Ballynameelagh, near Whitechurch, states that about the year 1852, when opening up a passage to a well in the rock cavity (No.

* See "Recent and Extinct Irish Mammals," by Professor A. Leith Adams, in the Proceedings of the Royal Dublin Society, Vol. II., N. S., p. 32, 1878.

13 in the list of caves, see part II., p. 180) he found a number of huge bones and a skull of very large size. These bones were unfortunately destroyed before they were determined.

In 1859 the late Mr. Edward Brenan, of Dungarvan, discovered in the Shandon cave remains of the mammoth, bear, reindeer, horse and other animals.*

The Shandon cave was subsequently visited and partially explored, in 1870, by Professors Harkness and Leith Adams.

In 1875, Professor Leith Adams, having obtained a grant from the Royal Irish Academy, still further explored it.† On both these occasions were brought to light many interesting remains of the above animals, all of which, including those found in 1859, are now in the Museum of Science and Art in Dublin.

The Ballynamintra Cave, which forms the special subject of this Report was discovered by the writer, when in search of bone-caves, in the year 1878, but owing to the lateness of the season it was not explored until April, 1879, when the excavations were commenced with Professor Leith Adams, who inspected their progress from time to time.

Mr. Kinahan subsequently made a careful survey of the cave, and the Plan and Sections were prepared embodying the results of notes taken from the commencement of the exploration.

II.—Physical Features of the Valley between the Blackwater and Dungarvan Bay, with a list of the Caves, by G. H. Kinahan, M.R.I.A., &c.

The valley lying between the Blackwater and Dungarvan, drained by the small rivers Colligan, Brickey and Finisk, is bounded on the south by the Drum (*anglice*, long low ridge) which is the dividing ridge between the two Decies, and on the north by the high ground that extends eastward from Cappoquin to Ballyvoyle Head, on the N.E. of Dungarvan (Plate X.) This valley, when the land was about 100 feet lower than at present, was occupied by an arm of the sea or estuary, the margins of which are now more or less perceptible.

The south margin of the ancient estuary can be easily traced on the north slopes of the Drum, consisting of terraces and sloping scarps, but the north margin is not as well marked. It can, however, be traced from near Ballyvoyle Head to Cappagh House, west of which, in the valley of the Finisk, it is indistinct, as a gradual slope of deep drift extends out from the hills for greater or less distances; as we approach Cappoquin, however, it is again well marked.

* See Proceedings of the Royal Dublin Society for 1859, and Dublin Natural History Review for October, 1859.

† See Transactions of the Royal Irish Academy, Vol. XXVI.

Dividing the valleys of the Colligan and the Brickey is a tract of high limestone ground which slopes slightly from Whitechurch towards Dungarvan, the ground above the Ordnance eighty feet contour line (the Ordnance zero plane is a mark on the Poolbeg Lighthouse, Dublin Bay, 8·094 feet below the mean level of the sea around Ireland) being margined by low cliff scarps or steep slopes. A detached tract of somewhat similar high ground occurs about Whitechurch House; while farther westward the ground between the Finisk and Blackwater, although as high as that just mentioned, has not its margins, except that to the eastward, as well defined. Besides the islands just enumerated, attention should be directed to the ancient channels. To the south there was a deep channel from Affane on the westward, to Killongford on the eastward; and from it "deeps" extended northward along the Finisk Valley and the N. and S. flat west of Whitechurch; while these branches joined into a second nearly E. and W. channel to the north that extends from Cappagh to Dungarvan. At the junction of the branches with the north channel, a little S. W. of Cappagh House, a great shoal accumulated, now represented by the hills of shingle, gravel, and sand, to the eastward of the Cappagh railway station.

The deposits characteristic of the channels are gravels, sands, and shingles, but in places in them there appear to have been deeper portions which subsequently formed lakes, and gradually were filled by accumulations of peat with its associated clays and marls. At times, during the raising of the peat by dredging for making turf, the bones of the Irish elk and red deer have been brought up, but of these Professor Leith Adams is of opinion, that the condition of the bones would indicate that "they came from the ancient lacustrine deposit (marl) under the peat;" bones of red deer, man and domesticated animals have also been found in the muds and sands of the Dungarvan estuary. In places in the Dungarvan estuary there are accumulations of peat similar to the submarine peats found in the neighbouring bays of Ardmore, (where a crannog occurs in it,) Whiting Bay; Youghal Bay which seems to have been called from the yew wood now submerged;* and various other places on the Cork coast.

The caves, the subject of the present inquiry, are generally found in the escarpment margining the high limestone ground, and those at present known are as follows—

Valley between Dungarvan and Cappagh.

Cave, No. 1—SHANDON.—was in the quarry near Shandon House. This has been entirely quarried away. No record has been kept of anything that may have been found.

* As suggested by the Rev. Canon Hayman in his Guide to Youghal.

Cave, No. 2—Shandon.—The cave made famous by Mr. Edward Brenan, who about the year 1859 discovered numerous mammalian remains in the cave breccia (Brenan and Carte, Proc. Roy. Dubl. Soc., Vol. II., p. 344. Leith Adams, Tran. Roy. Irish Academy, Vol. XXVI., p. 187.)

Cave, No. 3—Shandon.—A few yards further west in the same cliff.

Caves, Nos. 4 *and* 5—Shandon.—Opened in the cutting for the Dungarvan and Lismore Railway. Have still to be explored.

Cave, No. 6—Ballynamuck.—Unexplored.

Caves, Nos. 7 and 8—Ballynacourty.—Caves into which streams flow.

Cave, No. 9—Killeeshal.—A cave into which a stream flows.

Cave, No. 10—Coolnanav.—Called Ooanagoloor (*anglice,* cave of the sparrows). This cave is in the high ground a little to the southward of Nos. 7 and 8. It has still to be explored.

Cave, No. 11—Cappagh.—A swallow hole into which a stream flows.

Valley of the Brickey.

Cave, No. 12—Kilgreany.—In part quarried away. In the portion that is left records of man observed. Has still to be explored.

Cave, No. 13—Ballynameelagh.—In part quarried away. A deep well in one portion. Mr. Stack, the occupier of the adjoining house states, that in quarrying adjoining to the well a number of huge bones, one which they describe as "a huge head with great horns" were found. Smith, in his History of Waterford, states, that in the neighbourhood of Whitechurch a huge rib was got; possibly it may have been got in this locality, but of the exact place where it was found there is no record. (*See Note* 1, *page* 224.)

Cave, No. 14—Ballynameelagh.—A cave is said, by Mr. Stack, to exist in this brow a little north of last. (*See Note* 2, *page* 224.)

Cave, No. 15—Ballynameelagh.—A little north of last, partially explored, human bones were found. Dr. Leith Adams states that here there was evidently an interment, whether recent or not he is unable to determine.

Cave, No. 16—Bridgequarter.—Partially explored, floor of cave sixty-seven feet above Ordnance zero. Contains angular limestone shingle (weathering of roof) in brown earth, over broken blocks and cones of stalagmite in pale sandy earth under which is the solid limestone. The sides of this cave are worn and hollowed as if by water, and although it now opens to the north-westward it is said to have been found in a quarry, now filled up, in the

escarpment that forms the western margin of the N. and S. flat; or the same escarpment in which caves 14, 15, 17, 18, 19, occur. (*See Note* 3, *page* 224.)

Caves, Nos. 17 *and* 18—Ballynamintra.—Partially explored. The mouth of No. 17 is 70·37 feet, and that of No. 18 is 69·77 feet above Ordnance zero plane.

Cave, No. 19—Ballynamintra.—The cave in which the remains of man associated with extinct animals have been found, full particulars being given in the accompanying report of Messrs. Ussher and Leith Adams. The floor of this cave is 71·57 feet above Ordnance zero plane (*See Mr. Duffin's section,* Plate IX.)

Valley of the Finisk.

Cave, No. 20—Bridgequarter.—Usually known as the Fox earth in Whitechurch House demesne. Unexplored.

Cave, No. 21—Ballygambon Lower.—Entrance quarried away. Contains crystalline stalagmite floor, partially broken, over cave earth.

Cave, No. 22—Knockalahara.—Into which a stream flows.

Caves, Nos. 23, 24, 25, 26—Bewley.—Caves east and west of the Dun of Bewley. Unexplored. (*See Note* 4, *page* 224.)

Caves, Nos. 27, 28—Bewley.—Examined by Dr. A. Leith Adams, but considered unpromising.

Cave, No. 29—Carrigeen.—on the Blackwater.—Nearly quarried away.

Cave, No. 30—Dromana Rock.—on the Blackwater.—Unexplored.

The caves in the townland of Shandon (Nos. 1 to 3), although on the continuation of the Whitechurch and Cappagh escarpment, are at a much lower level than the others, the floors at their entrances being not more than ten or fifteen feet above H. W. M. The floor of cave No. 19 is seventy feet above the Ordnance zero plane (see Duffin's cross-section on map, Plate IX.), that is nearly seventy-nine feet above the mean level of the sea. From these no evidence of man has, as yet, been obtained. The name of the place (*Anglice*, ancient fort), would suggest that at an early period it was a place of note; furthermore on the cliff, a little west of Brennan's cave, there is a kitchen midden, as yet only partially explored. Nearly half of the other caves for different reasons, principally on account of their drainage give no promise of containing animal remains.

From the evidence with which we are at present acquainted I would suggest:—

1st. The caves of this valley were connected with a subterraneous drainage when the land was at a higher level than at present. [Adams' Report, Trans. Roy. Irish Academy, Vol. XXVI.] Some of these caves may have been at the time open to daylight, but others of them were exposed by subsequent denudation.

2nd. After the first formation of the subterraneous passages and openings, the form of many of them was altered and modified by some such water action as that due to the waves at the margin of an estuary or large lake.

3rd. A time when the caves were more or less filled by sand, gravel, and shingle; the sand and gravel evidently are water drift carried into the caves. These accumulations, by the infiltration of limy matters, were in part changed into "gravel-stone" and "shingle-stone," while masses of stalagmite were deposited on them. In the lower sand and gravel, no animal remains have as yet been found, but in the crystalline stalagmite, immediately on them, bears' bones, &c., occur.

4th. The lower gravel and sand partially removed, and the stalagmite flooring partially broken up.

5th. The caves possibly inhabited by man, during which time they were in part refilled with the "pale sandy earth," imbedding the blocks of the broken-up stalagmite.

6th. The mineral and earthy accumulations of this cave augmented, by the deposition of limy matters, by materials carried into them along the subterraneous passages, or by falling into them through "chimneys," the more or less vertical openings to the surface; or, in some cases, the rocks near the entrance of a cave may have weathered into shingle and fallen into it.

In connexion with these caves it may be mentioned that, in addition to the kitchen midden at Shandon, there is, on the escarpment near Whitechurch, townland of Ballykennedy, in a *lis* or clay fort, a kitchen midden; while in the vicinity of the Bewley caves are the ruins of a *dun* or hillfort. It is hardly necessary to point out that these indications of human occupation refer to men who occupied the country probably up to very recent dates, and long after the time of the cave deposits.

III.—Structure and Contents of the Ballynamintra Cave, by R. J. Ussher.

Situation of the Cave.

As referred to in the second portion of this report, the limestone tract between Dungarvan Bay and the Blackwater is broken, near Whitechurch and Cappagh, by the gravel-flat, running north and south, on which the Cappagh railway station stands. This flat merges towards the south, by a gentle fall, into the remarkable trough along which the sluggish Brickey, skirting the northern slope of the Drum, runs into Dungarvan Bay. Rocky scarps of limestone in many places flank this gravel flat, both along its eastern and western sides, and rise, in the neighbourhood of the Ballynamintra cave, to ninety-six or ninety-eight feet above the Ordnance zero level, the flat ground between them being forty feet lower, and marked fifty-eight feet on the Ordnance sheet.

About the seventy feet contour line, a series of caves occur along the scarp, west of this flat; and in three of these, besides that of which we are about to speak,

were found the broken masses of crystalline stalagmite embedded in pale sandy earth similar to that hereafter described. Not only do these caves show that they were excavated by water in their interior, but also in numerous places along the scarp the rocks, both on the cave horizon and below it, are under-cut and have the worn appearance common in sea and lake cliffs. Upon the high ground of which the scarp is the margin the drift consists chiefly of rolled pieces of sandstone similar to those which occurred so frequently in the two upper strata within the cave, and which there often bore marks of human use. The cavern in question is about half a mile south of the railway station, from which it can be seen. It faces E. N. E., and its floor is about twelve feet above the flat ground in front, as shown in the section (Pl. IX.), for which we are indebted to the kindness of W. E. L'Estrange Duffin, Esq, County Surveyor.

Description of the Cave.

The cave forms a horizontal tunnel averaging ten feet wide for a length of nearly thirty feet, after which it widens and its roof rises very considerably in an irregular manner. It has been excavated for forty-three feet, beyond which its extent is not ascertained. It was nearly filled to the roof, with strata presenting the following general section.

No. 1.—The brown earth, with rounded sandstones, limestone fragments, charcoal, bones and implements, eighteen inches to twenty-four inches in depth.

No. 2.—The grey stratum, earth and calcareous Tufa,* with rounded sandstones, limestone fragments, charcoal, bones and rude implements, fourteen to twenty inches in depth.

No. 3.—The pale sandy earth, with pebbles, bones and occasionally charcoal.

No. 4.—The crystalline stalagmite, in broken cuboidal masses, or in a continuous floor, with bones and teeth of bear and deer, one foot to three feet six inches in depth.

No. 5.—The gravel, barren of animal remains, and resting directly on

No. 6.—The limestone floor.

In no part of the cavern was there any accumulation of red soil or cave-earth.

As these materials were removed they were carefully examined, nothing being left but some of the bottom gravel. Beyond twenty-three feet within the entrance no remains of extinct animals nor traces of man were found; yet the excavations were carried on as far as forty-three feet, where they were discontinued from the difficulty and apparent fruitlessness of the search. Excavations from four to six

* This term is hereafter restricted to the newer limy deposit in distinction to the older or crystalline stalagmite.

feet deep, were also continued for twenty feet outside the present mouth of the cave, between the flanking walls of rock, which form continuations of the sides of the cave, and indicate that it formerly extended further out. That such an extension of the cave once existed is shown by a stalagmite floor with upright cones coating a bench of undisturbed gravel, (the continuation of No. 5) fourteen feet outside the present entrance, and more than four feet below the recent surface. This must have been formed by water dripping from a roof of rock that is now gone, and extended at least sixteen feet outside the point where a continuous roof now commences, so that objects found in the accumulations within these limits evidently belong to the true cave deposits.

It has already been mentioned that the rocks in the vicinity of this and the neighbouring caves have a water-worn appearance. This is perceptible at from seventeen to twelve feet outside the cave's mouth, on the left * side, a little below the datum level, where a bench of the limestone rock is remarkably smoothed and rounded; while the left wall from the latter spot inwards exhibits a singular hollow curve, shown in cross sections A to E on Plate XI. The roof also for the first twenty-four feet has an arched, worn appearance, its angles having been rounded off, and the walls in other places are similarly worn. These facts seem to prove, for reasons stated below, that the cave was originally shaped by water.

The hollow curve in the left wall (which is best shown in cross-section B) ceases about 18 inches below the datum level. Similar hollows or grooves occur in the sides of Brixham cave, and these are supposed by Mr. Pengelly to have been worn by a stream, having a very limited vertical range, that flowed through it at a time when the lower part of that cave was filled with some accumulation capable of protecting the walls up to the level at which the hollow curves commenced. In corroboration of such a theory in the case of the present cave it may be mentioned that, on the left side from near the mouth to nine or ten feet outside it, a bench of gravel, more or less brecciated, lay undisturbed against the rocky wall, as shown in cross-section A. The top of this gravel-bed was nearly on a level with the bottom of the hollow curve in the rock, but did not cover any of the latter, and it may show the general level at which the gravel in this cave stood at one period.

On the right side was a range of swallow holes, shown in cross-sections A and B. These were concealed by the upper strata, but at a greater depth were found to be empty. One of them, however, on being opened out was found at some depth to be choked with pebbles, blocks of brecciated gravel (fifth stratum) and broken pieces of stalagmite (fourth stratum) surrounded by pale sandy earth (third stratum) showing that the contents of the cave had a tendency to be carried down these swallow holes, which were very plainly enlarged and worn out of the rock by water and detritus. The smooth surface of another of them exhibits little buttons of calcareous matter such as are formed in cavern pools. The cave's floor dips from

* The terms "right" and "left" are hereafter used with reference to a person entering the cave.

left to right towards these swallow holes, and in their vicinity the lower strata dipped likewise towards them, and appeared to be mixed with each other and with rounded stones.

On both sides of the cave were water-worn crevices in the walls, often empty or but partially filled, which seem to have served as channels for drainage after the centre of the cave had been filled up.

At ten feet from the cave's mouth, on the right, a fissure in the limestone commenced at a high level and sloped down to the swallow holes at the entrance. It formed a channel down which the calcareous tufa ran, as hereafter described. This and other fissures yielded numerous bones and some implements, generally embedded in a loose, dark earth, or cemented into a breccia by the calcareous tufa.

In cross-section D the arched part of the roof is shown to terminate in a pendant point or ridge, to the right of which it rises into one of those irregular shafts or "chimneys" which probably once served as channels for water from above, its sides being worn. Under this chimney the inhabitants of the cave might have resided, even when the main part of the cave was filled with accumulations. Here on the rock-surface, at ten to eleven feet inside the cave, and from six to twelve inches above the upper stratum, are a number of short transverse markings or scorings in a film of stalactite. They appear to be artificial, but cannot be recent, for when they were discovered the deposits had accumulated to such a height in the cave that this "chimney chamber" could only have been reached from without by a small animal.*

Further proofs that it was a special resort of the human inhabitants are afforded by the quantity of charcoal found in the neigbourhood of the chimney in the upper strata, and by a hammer-stone found here in the grey earth (Plate XIII., fig. 11), which bears the clearest marks of human use.

The roof of the cave, as stated above, is arched and worn smooth. After dipping rapidly inwards for the first three feet, it becomes then nearly horizontal. From the fourteenth to the twenty-second foot the roof of the main tunnel dips gently inwards and is flattened from right to left, being still water-worn. On no part of the roof mentioned hitherto is there any stalactite, but a mere recent film. From about the twentieth foot inwards the roof is more irregular, being covered with a deep, hard coat of the calc tufa now adhering to it, though this limy matter must have formed upon the top of the earthy strata, which beyond twenty-four feet from the entrance nearly touched the roof. The little remaining space was completely filled with the calcareous coating, except that two arched tunnels or water-ducts, only large enough to admit a fox or rabbit, traversed it, dipping outwards from the inner cavity to be described hereafter.

* Mr. Kinahan on inspecting these scorings considered them to be artificial, but Professor Leith Adams and the Rev. James Graves, who saw them subsequently, expressed doubts on the matter.

Stratified Deposits.

No. 1.—The Brown Earth.

This was, with the exception of loose stones on the surface, everywhere uppermost for twenty feet inside the cave. Outside the cave's mouth it merged into the loose vegetable soil, but within it was often densely packed. Its depth was generally from eighteen to twenty-four inches. It contained limestone fragments, angular bits of chert, and rounded sandstones from the drift. These materials, forming the staple of the stratum, correspond with the materials forming the surface on the cavern hill. In cross-sections C and D, beds of stones and pebbles appear in the brown earth. These were almost quite free from the earth, though it lay over and beneath them, but bones and charcoal were often met with among them. A similar bed of stones, shown in cross-section E, ran along the left wall on the surface. At seven feet outside the entrance the surface was about eighteen inches higher than it was at the cave's mouth. This may be attributed to earth having rolled off the hill above; the overhanging rocks that flank the entrance of the cave (and probably formed its continuation) not permitting such earth to fall closer in. From this point outwards the surface rapidly fell away.

The brown earth contained great numbers of remains (the bones being usually in fragments and of a yellow colour) of rabbit, hare, goat, ox, fox, pig, red deer, dog, marten, horse and hedgehog, as well as of several birds, the animals first in this list being the most numerously represented. Among the relics found in the brown earth we have also one metatarsal of bear, darker than the former bones, a number of broken bones of the Irish elk, blackened and exhibiting dendritis, as well as the fragments of a human skull, several of the latter also marked with dendritis, and other human bones, all which, except the bear's metatarsal, were found not far from the cave's mouth at the outset of the explorations.* This blackened and dendritic appearance was more characteristic of the bones in the second or grey stratum than of those in any other. Nearly every bone of Irish elk found in the cave was thus marked, while the remains of domestic animals found in the same part of the cave with the blackened relics just mentioned had no such markings.

The bones in the brown earth from about the tenth foot inwards appeared still more recent, and many were in all probability brought in by foxes, who as well as rabbits had undoubtedly inhabited the inner cavity beyond the part we are now treating of, for burrows were found in the earthy accumulations beyond thirty feet from the entrance, to which the tunnels in the calc tufa served as entrances. No burrows however were found in the open part of the cave outside these tunnels, nor any appearance of the strata having been there disturbed by them.

In this stratum charcoal was frequent, and found everywhere. Its last

* Owing to the obscurity of the section where these bones marked with dendritis were found, it is quite possible that they may have belonged to the second rather than to the first stratum.

occurrence was at twenty-three feet from the mouth, where the brown earth almost touched the roof, and beyond which the cave was completely filled to the roof with accumulations. Several objects of human art occurred in this stratum. Close outside the cave's mouth, under the flanking wall to the right, was found in dark surface loam, by Professor Leith Adams, with bones of hare and goat, a polished celt (Plate XIII., fig. 5). Under the right flanking wall was also found, seven feet outside the entrance, a large flat amber bead (Plate XIII., fig. 8). At fourteen feet within the entrance, by the left wall, there occurred in one of the beds of pebbles above-mentioned, and in the lower part of the first stratum, a long slender implement of carved bone (Plate XIII., fig. 3). Near this was the carved perforated bone (Plate XIII., fig. 9). There was also found either in the brown earth or the next stratum a small, flat, pointed bone implement (Plate XIII., fig. 6), like the point of a netting needle broken off, and among the debris of various strata thrown out of the cave, two fragments of a vessel of rude hand-made pottery with indentations on the lip, and charred internally by fire (Plate XIII., fig. 7). The bone chisel (Plate XIII., fig. 4), and the knife handle (Plate XIII., fig. 1), found in crevices of the rock may possibly have been of the same period as this stratum, as they lay in fissures of drainage that lead down from the horizon of the brown earth. Several of the sandstones found in the brown earth exhibit marks of human use similar to those so observable on stones from the second stratum. No. XLIV. is a tapering piece of purplish sandstone. It was ground down on both sides at the tapering end. This implement was found more than twenty feet outside the cave's mouth in the brown earth. The striking-stones, Nos. XLVII. and XLVIII. are worn, flattish sandstones, whose edges are chipped, as if they had been used by man. They occurred in the same stratum, twelve feet within the cave's mouth.

No. 2.—The Grey Earth and Calcareous Tufa.

Under, but clearly defined from the brown earth, was a grey stratum, its staple consisting of earth, rolled sandstones, and limestone fragments, apparently similar to the materials of the first stratum, but usually pervaded by carbonate of lime in the form known as calc tufa, some of which was in the friable state that has been called "lime froth." This flood of calcareous tufa ceased outside the mouth of the cave (where the earth of the second stratum was only distinguishable from the brown earth by its paler colour). This calcareous material was first found choking some of the crevices in the right wall that sloped down to the large swallow-holes into which it apparently had flowed. In these crevices it formed a breccia containing bones of Irish elk, wolf, and bear with pebbles. On tracing it backwards from the cave's mouth it was found permeating the earth of this stratum, to which it imparted its general grey colour, and in which it formed distinct whitish seams. From the fifteenth foot inwards on the left side of the cave this calcareous substance was found but a few inches in depth and free from admixture. It formed a hard

whitish cake, covering another layer of the same substance, but in a wet state like fresh mortar. The latter lay directly on the crystalline stalagmite floor. (This whitish cake is of special interest, for in and upon it was found the greatest assemblage in the cave of human bones and other traces of man, though it was not more than two feet six inches from the roof.) Still tracing the calcareous tufa we find, as before stated, that beyond twenty-three feet from the cave's mouth the earthy accumulations nearly touched the roof, and the white cake of calc tufa that formed upon them became cemented to the roof to which it now adheres, none being here found on the stalagmite floor. From this point inwards it may be said to represent the second stratum among the accumulations of the inner cavity. Proceeding still further in, the calcareous sheet was traced to the great chimneys or roof holes at thirty and at forty feet from the cave's mouth. To their sides it was found profusely adhering in a breccia with limestone fragments, and thence sloping away on the earthy accumulations towards the outer part of the cave, marking the course in which it had flowed.

The grey earth must have accumulated while water charged with carbonate of lime occasionally flowed through the cave from within, filtering through the earth, and leaving white layers.

This stratum yielded most interesting relics of man and extinct animals. The bones it contained were not confined to one locality, but they were frequently clustered together under the cave walls and in crevices of the rock. They were usually to be distinguished from the bones in the brown earth by being blackened and covered with pale dendritic marks, but most of those in the crust of calc tufa were straw-coloured. The greatest finds of bones were within ten feet of the cave's mouth, whether inside or outside it, within which limits nearly all the blackened bones marked with dendritis in either stratum occurred. A large proportion of them belonged to the Irish elk. These represented at least five individuals, but probably more. There were numbers of fragments, but no large bone entire. The ends of the marrow bones were always broken off, and the shafts generally split lengthways. Many of the shafts show longitudinal cracks. Fragments of the antlers were found, and portion of an upper jaw, but no teeth. Several of the extremities and shafts of bones and antlers show indentations as if they had been gnawed by large carnivores, but such instances are few. The small bones of the limb-joints and feet were numerous. A human vertebra, a radius, and one or two phalanges found in the grey earth, as well as several bones of bear, were blackened, but among the straw-coloured bones encrusted with calc tufa there was an assemblage of fragmentary human remains at about sixteen feet from the cave's mouth. One left radius was found here, and another left radius at the tenth or eleventh foot in this stratum. With the above bones in the calc tufa were associated remains of hare, ox, red deer, pig, a vertebra of Irish elk (very black, unlike the rest in colour), shells of Helix and lumps of charcoal, while near

them in this second stratum were the chipped hammer stones, VI. and VII. (Plate XIII., Fig. 10), with a marine mussel shell and a limpet which occurred at from sixteen to nineteen feet from the cave's mouth.

In the grey earth were found, besides remains of the above mammals, eight bones of rabbit, four of goat, and one each of fox, wolf, badger, and marten.

Charcoal occurred in this stratum even more abundantly than in the brown earth. It formed a seam in the midst of the grey earth, like an old floor or hearth, resting on one of the white calcareous seams. Detached lumps of charcoal occurred both above and below this charcoal seam.

The only bone implement from this stratum is the pointed metacarpal of a goat, or other small ruminant, apparently worn by use (Plate XIII., fig. 2). This, however, does not bear the stamp of great antiquity, as its colour is pale. No implement found appears to have been formed from the bones of the Irish elk, nor possesses the dendritic marks characteristic of this stratum. Rude stone implements however were plentiful. Worn lumps of sandstone from the drift, of shapes convenient for using in the hand, were found through the grey earth. These, which are fully described in the list of implements, show unmistakable marks of having served for striking and cleaving with, possibly for smashing the bones to get at the marrow. The rudeness of these implements is as striking as their antiquity, associated as they were in the same stratum with remains of the *Cervus megaceros.*

Crevices.

It may here be the place to mention that the animal remains lodged in the crevices of the rocky walls, though often at a greater depth than the horizon of the grey earth, partake of all the characters of the bones found in that stratum. A large proportion, thirty-three, of them belonging to the Irish elk, were broken, and marked with dendritis. The other bones from the crevices were of hare twenty-nine; deer eight; bear six; pig three; wolf one; rabbit one; and one human phalanx.

The implements found in the crevices consisted of a bone chisel (Plate XIII., fig. 4), and a knife handle (Plate XIII., fig. 1), also a rude celt, No. XXVIII., found with the latter. A few bits of charcoal also occurred in the crevices.

No. 3.—The Pale, Sandy Earth.

Under the grey earth was an arenaceous calcareous stratum, from which the argillaceous matter seemed to have been generally removed by water. It effervesced slightly with mineral acids. It was of a pale brown, inclining to ochre, and passed in some places into a gravelly sand with small pebbles of old red sandstone; in other places it was fine and compact having an aspect like that of a clay. It had no resemblance to the two upper earthy strata, and was only found, as a rule, where the stalagmite, next to the described, was broken up. It reached inwards

fourteen feet from the cave's mouth, where the stalagmite floor was unbroken. Here the pale sandy earth was found underneath it, but a little further in it disappeared, the space under the stalagmite being hollow. From the above point (where it was last seen), outwards as far as the excavations went, this pale sandy earth enveloped and adhered to the broken masses of stalagmite, hereafter mentioned, which lay embedded in it in the greatest confusion. It coated their surfaces as if it had been deposited by water, and it was found filling cracks and interstices in the stalagmite floor where the latter was in place, but partially disjointed, as at eight feet from the mouth. (See cross-section C.) This stratum rested on the gravel, which was the lowest in the cave, and in the vicinity of the swallow-holes, shown in cross-sections A and B, it was in places mixed with the gravel where it dipped towards those orifices. Here were found in it many rolled lumps of limestone exhibiting striæ, one of which, No. III., has on one side three pits, each of which contains three furrows, and on the reverse side more furrows less distinct. Whether these strange markings were artificially made or not remains to be decided. Near the above was a rounded lump of sandstone, No. II., with flat faces on the opposite sides produced by rubbing. Both these stones suggest that they were used by man for some purpose, though their artificial character is doubtful, and nothing else resembling an implement was found in the pale sandy earth. Even the above were found near the swallow-holes, where there may have been some disturbance of the stratum by water.

Near the swallow holes, and at a depth of five or six feet below the datum level, were also found in this stratum an assemblage of bones of bear, similar in size to bones of the same species that were in the stalagmite a few feet further in, and as corresponding bones of the right and left sides were found in this pale sandy earth, and in the stalagmite respectively, it is very possible that they belonged to the same individual. Moreover, those bones found in the stalagmite seemed to have been embedded in it entire, while those above mentioned in the pale sandy earth had been broken, apparently after they were fossilized (though in other respects their condition was similar). They plainly had not been subjected to any great force, for their brittle angles and edges retained their sharpness, and broken portions of the same bone were found near one another.

The great majority of bones in this stratum were of a pale buff tint, like those in the stalagmite, and, like them, were heavy, highly mineralized, and very brittle; though, unlike them, these had occasionally black spots and traces of dendritis. They were utterly dissimilar from the bones in the two upper strata, which were comparatively light, and far less mineralized; while the latter differed in colour from those in the third and fourth strata. The pale sandy earth contained forty-three bones of bear, twenty-three of hare, five of pig, one of rabbit, one tooth of wolf, and one bone each of deer, ox, and Irish elk. The two latter having been found under a large piece of the stalagmite floor in clayey earth, were at first

supposed to have been deposited there previously to the formation of the stalagmite, but are now believed to have been introduced at a more recent time and to belong to the stratum we are treating of, for the following reasons. The stalagmite (as we shall see) was formed directly on the gravel. In all that portion of the cave around where these two bones (of Irish elk and ox) were found the stalagmite had been broken up and lay in this pale sandy earth, which seems to have found its way into every crevice, and to have filled hollows under as well as between the masses of stalagmite. As, therefore, these two bones were neither found in the stalagmite nor in the gravel, but in the stratum now under consideration, it is very possible that like it they were more recent than the stalagmite, though found beneath a mass of it. Certain peculiarities in their condition and colour also lead to this conclusion.

Among the bones from this stratum the only instance of human remains is a phalanx or finger-bone, said by the workmen to have been found in the pale sandy earth, on an occasion when they unfortunately were by themselves, though in its blackened appearance it resembles the bones from the grey earth above.

Bits of charcoal occurred occasionally in this stratum, one of which was five feet below the datum level, though this was near the swallow-holes. (See cross-section B.)

Traces of man in the pale sandy earth appear, therefore, to be few and doubtful, while the species of animals though fewer were all represented in the second stratum. A shell of the common garden snail was found with a bone of pig at a depth of six feet from the surface in this stratum, near the swallow-holes. Shells of several species of Helix were commonly found in the first two strata, and even in the pure calc tufa.

No. 4.—*Crystalline Stalagmite.*

In every part of the cave this deposit, though sometimes shattered, was found, always buried under the preceding strata, and either resting on or bearing traces of the gravel (the lowest stratum in the cave), which remained adhering to the stalagmite blocks and incorporated with them on their lower side. The stalagmite was generally more or less crystalline, sparkling when broken ; and in one part of the cave the lowest layer of it, which formed the ceiling of a curious hollow mentioned below, was made up of a mass of small, transparent, vertical crystals, of a yellowish tint. Much of the stalagmite was however opaque, exhibiting lines of deposition, of a pale fawn-colour, but occasionally containing peculiar ferruginous masses. In more than one instance a stalagmite column was found embedded horizontally in the stalagmite floor. From the twelfth foot inwards this floor extended across unbroken from wall to wall (see cross-sections D, E, and F) ; but outside that limit the stalagmite was all found broken up and disturbed (except some by the walls), and lay embedded in the pale sandy earth last described, a few

of the blocks protruding into the upper strata close to the surface near the entrance. Where this break-up had taken place, as shown in cross-sections A, B, and C, the cave is wider and the right wall overhangs, so that it could have afforded no side-support to the stalagmite floor, while in cross-sections D and E the reverse of this is shown to be the case. The blocks of stalagmite showed evident traces of separation from the portion of the floor that was still *in situ,* for they were cuboidal, and had lines of stratification. Many of them were very large; one, for instance, measuring 3 ft. 6 in. by 3 ft. by 1ft. Though sometimes tilted in a slanting position, they were not heaped together, but strewed the whole area where they lay, and no marks of rolling appeared on them. This shows that whatever agency had broken up the stalagmite floor had not removed it when broken. Several large cones, like sugar-loaves, besides bosses and columns partially covered with crystals were found, all broken off and lying among the rest of the broken floor, but only one stalactite was met with, which was eighteen inches long, and in three pieces that lay close together. It is remarkable that no stalactites, nor even traces of their roots, should have been found on the roof of the cave, except some that are plainly recent on the roof of the chamber to the left, shown in cross-section F. The blocks were strewn through the space between the flanking walls outside the entrance, and were very abundant at seven feet from it (see cross-section A), where the surface was highest, some occurring just under the upper stratum. They continued to occur out as far as twenty feet where they were associated with blocks of consolidated gravel.

From two feet to six feet inside the cave's mouth a mass of the stalagmite floor, that was no doubt broken off and disconnected from the rest, was found to contain in its lower portion, next the gravel (some of which was cemented to it), jaws and other bones of a large bear. They appear to have been deposited in the flesh, as adjoining bones of the skeleton were found together. Near them was also embedded in the stalagmite a metacarpal bone of deer with characters of reindeer. In another mass of the same material were three or four molar teeth of red deer. With the exception of some bones of frog, the above were all the animal remains yielded by this stratum, which contained no trace of man. In the unbroken portion of the floor, from twelve feet inwards, no animal remains whatever were found.

Within the cave's mouth, from two feet inwards along the left wall, was a bench of stalagmite obviously in its original place (see cross-section C), yet it separated freely into blocks which had the pale sandy earth between them, while charcoal was in one place found in its interstices on a level with the charcoal seam in the grey earth close by. Water seems to have run behind this stalagmite bench, as, on its removal, were found behind it water-worn crevices in the rock leading down to a small empty swallow-hole that emitted a draft. In a recess of the rock covered by this stalagmite mass were a bone knife-handle (Plate XIII., figs. 1, 1A), and a rude celt with some small bones of bear, but as this recess was

evidently in a descending line of drainage it is possible, as stated previously, that the objects it contained may have been drifted into it from the upper strata, as in the case of the crevice containing the chisel. The undisturbed bench of stalagmite just mentioned, together with the bench of gravel lying along the same wall further out (see cross-section A), seem to show that whatever denuding agencies may have disturbed the centre and the right side of the cave, where the great swallow-holes were, the left side was comparatively free from their influence.

At nine feet from the entrance solid stalagmite adhered to the right as well as to the left wall, but from twelve feet inwards the stalagmite floor was continuous, adhering firmly to both walls, and exhibited no cracks nor signs of yielding. It was from two feet to three feet six inches in thickness, and was quarried away with the greatest difficulty. The surface of the floor where unbroken was remarkably free from cones or bosses, such as were found frequently among the broken portions of it.

Proceeding inwards, the cave's roof was found to dip, while the stalagmite gradually rose, so that beyond twenty-four feet from the entrance the surface of the latter was only from six to twelve inches below the roof.

Tracing it into the inner cavity, at twenty-six feet from the entrance, the stalagmite floor sloped rapidly upwards against the right wall to a much higher level. Immediately further in, the roof suddenly changed into a great vertical shaft (shown in cross-section F). This suggests that the calcareous water which formed the great mass of stalagmite, was largely introduced into the cave in the place marked by this slope in which the floor culminated. From this point it fell away very rapidly to the left, and more gradually towards the outer part of the cave.

Under the solid mass of stalagmite was a remarkable Drusic cavity, first observed at fifteen feet from the entrance, but extending inwards to the twenty-eighth foot where it became subdivided. The floor of this hollow was the gravel (No. 5,) solidified to some depth by calcareous matter, on which were strange stalagmite growths like coral or petrified moss. Its roof was the solid stalagmite, the surface of which was covered in some places with clusters like candied fruit, and in others with sharp crystals. Having found very similar growths* in still pools in the stalagmite of other caves, I should say that the above hollow was once a pool in which the carbonate of lime was precipitated in these strange forms, and over which the great mass of stalagmite gradually crept until the pool was roofed across, while the water subsequently draining off left this hollow empty.

No. 5.—The Gravel.

This deposit, which lay directly on the limestone floor, was very uniform in character and contained no object of interest. It was of small size, composed of

* The formation of similar growths is described and illustrated in "Cave hunting," by Professor Boyd Dawkins, p. 65.

rounded and subangular fragments of the Old Red Sandstone and other rocks, but not of limestone. These were mixed with an impure brown sand. Its upper portion was often solidified by calcareous infiltration, and when broken formed hard blocks.

The high bench of gravel on the left side (shown in cross-section A), had seams or layers in it of the same material as the stalagmite floor. That the entire gravel-bed in the cave was probably once on a level with this bench, will be set forth in the sequel, where the causes of its denudation along the centre and the right side of the cave will be suggested. So far as was ascertained, this lowest stratum extended through the inner cavity, where, as elsewhere, the stalagmite floor reposed on it.

The Inner Cavity.

Beyond twenty-four feet from its mouth the cave loses its tunnel shape, expanding into two irregular chambers divided by a depending ridge (as shown in cross-section F). In each of these divisions is a great upward opening, whose height has not been ascertained. Both these "chimneys" as well as the entire of the inner cavity (with the exception of part of the left-hand chamber), were completely filled up.

The gravel and the stalagmite floor resting on it were the only strata that here retained their typical characters. The surface of the stalagmite, which betrayed signs of disintegration except on the right side, was at a considerably lower level in the inner cavity than it was a little further out, and to it adhered a light brown very tenacious clay, passing upwards into brown, sandy loam, densely packed. Both the clay and the loam above it contained local and transported fragments of limestone, and of Old Red Sandstone, such as were common throughout the upper strata of the cave, but in the part we are now speaking of, limestone in rubble and in large blocks was much more frequent. These, as well as the sandstone lumps, were often cemented in a breccia to the roof and to the sides of the chimneys by the calcareous tufa, which was here very profuse, and which had formed upon and partly pervaded the earthy accumulations, descending along them in a sheet towards the outer part of the cave. In the left-hand chamber it had formed a white seam or floor upon the earthy debris. Above this, brown earth, indistinguishable from that below, was found, in places touching, the short, recent-looking stalactites that here alone depended from the roof.

The stones and earthy contents of this cavity, as well as the calcareous tufa, justify us by their similarity to the materials of the first and second strata in the outer part of the cave in correlating them, and in supposing that the latter were derived from within. One striking difference, however, must again be noted. After the Irish elk's jaw and ulna, found at twenty-three feet from the entrance, no ancient animal remains occurred further in, nor any traces of man.

IV.—Report on the Animal Remains, by A. Leith Adams, M.B., LL.D., F.R.S., Professor of Natural History, Queen's College, Cork.

The following remains of Mammals, Birds, Amphibians, and Invertebrata, found in Ballynamintra Cavern have been identified with certainty :—

Mammals.

Man.	
Horse, ...	*Equus caballus.*
Pig, ...	*Sus scrofa.*
Ox, ...	*Bos longifrons ?*
Goat, ...	*Capra hircus.*
Red Deer, ...	*Cervus elaphus.*
Irish Elk, ...	*Cervus megaceros.*
Grisly Bear, ...	*Ursus ferox* (Race *spelæus*).
Badger, ...	*Meles taxus.*
Wolf, ...	*Canis lupus.*
Fox, ...	*Canis vulpes.*
Dog, ...	*Canis Hibernicus ?*
Marten, ...	*Martes sylvestris.*
Hare, ...	*Lepus variabilis.*
Rabbit, ...	*Lepus cuniculus.*
Hedgehog, ...	*Erinaceus Europœus.*

Birds.

Waders, ...	*Grallæ.*
Perchers, ...	*Passeres.*

Amphibians.

Frogs, ...	*Batrachia.*

Mollusca.

Mussel, ...	*Mytilus.*
Limpet, ...	*Patella.*
Land Snail, ...	*Helix.*

Man.

The external appearances and mineral characters of the human bones differ in no way from what obtain in the other animal remains, with which they were associated.

The few long bones, although violently broken, do not present the solutions of continuity in their long axes so apparent in the elements of the appendicular skeleton of the Irish elk and other ungulates, and the pell-mell dispersal of the fragments clearly show that they had not been deposited in the flesh.

Excepting a few metatarsals, no other parts of the skeleton were found in their natural positions, thus showing that they had been first broken, and were subsequently strewn indiscriminately throughout the respective deposits.

The two proximal fragments of left radii (Nos. 203, 239) not only prove the existence of two persons, but that one bone is larger than the other. In the case of the supra orbitals, there is nothing to show that they may not have belonged to the same individual, and whilst the ridges are more pronounced than in the generality of crania of civilized races, these prominences are in no way very remarkable.

—	Right or Left.	No. 1.	No. 2.	No. 3.	No. 4.	Crevices.	Debris thrown out of cave.
Supra-orbital,	1 L, 1 R.	2	.	.	.	.	.
Frontal,	—	2	.	.	.	.	.
Parietal,	—	4	.	.	.	.	.
Temporal,	1 L.	1	.	.	.	.	.
Occipital,	—	2	.	.	.	.	.
Supra-occipital,	—	1	.	.	.	.	.
Ex-occipital,	—	1	.	.	.	.	.
Canine,	—	.	1	.	.	.	.
Premolar,	—	2	.	.	.	.	.
Cervical,	—	1	1	.	.	.	.
Rib,	—	.	2	.	.	.	.
Clavicle,	1 L.	.	1 ?	.	.	.	.
Radius,	1 L, 1 L.	.	2	.	.	.	.
Ulna,	1 L.	.	1	.	.	.	.
Third Metacarpal,	1 R.	.	1	.	.	.	.
Fifth Metacarpal,	1 L.	.	1	.	.	.	.
First Phalanx, 4th or 5th Metacarpal,	—	.	.	1	.	.	.
Femur,	1 R.	.	1	.	.	.	.
Fibula,	1 L.	.	1	.	.	.	.
First Metatarsal,	—	2	.	.	.	.	.
Third Metatarsal,	1 L.	.	.	.	.	.	1
Fourth Metatarsal,	1 L.	.	.	.	.	.	1
Fifth Metatarsal,	1 L, 1 R.	1	.	.	.	.	1
First Phalanx, 4th Metatarsal,	—	.	.	.	.	1	.
	—	19	12	1	.	1	3

The remains recorded from No. 1 Deposit are doubtfully referred to this stratum for the reason that they were found at the outset of the excavations, and before the two uppermost deposits had been satisfactorily differentiated. The blackened and dendritic appearances of the surfaces of several of these remains from No. 1 are so like the Irish elk's and other bones of No. 2, and the fact that there was not always a very pronounced line of demarcation between the two uppermost deposits, make it not improbable that all the human bones were derived from No. 2 deposit. The same might apply to the bones found in the crevices and in the *debris* after the removal of the latter. The finger bone from No. 3 may have fallen into a crevice in the latter deposit, and become enveloped in its pale sandy earth.

The Horse (*Equus Caballus*).

Three molars, discoloured, and a fragment of a metacarpal, of a pale, yellow colour, were obtained from No. 1. The horse and bear were associated in the neighbouring cavern at Shandon, so that their co-existence is not remarkable. The teeth show also a small horse.

Pig (*Sus scrofa*).

This ungulate, one of the feral mammals of Ireland in historical times, has been identified among the exuviæ of No. 3 deposit in Ballynamintra cave, where teeth and bones were found. Its remains, however, were most plentiful in No. 1, as follows :—

—	No. 1.	No. 2.	No. 3.	Crevices.	Debris thrown out of cave.
Teeth,	2	7	1	3	1
Cranium,	3	.	.	.	.
Mandible,	5	1	.	.	1
Vertebræ,	.	1	.	.	.
Scapula,	.	1	.	.	.
Humerus,	.	1	.	.	.
Metacarpals,	.	4	2	.	.
Metacarpals or Metatarsals,	6	1	.	.	.
Femur,	1	3	.	.	.
Astragal,	1	.	.	.	.
Phalanges,	5	.	2	.	1
	23	19	5	3	3

The bones of young individuals, and the fragmentary condition of the remains generally, in the two uppermost deposits suggest that the pig may have entered into the dietary of the early human, as well as of the quadrupedal inhabitants of the rock cavity.

Ox (*Bos longifrons?*).

Remains of a small ox, of the dimensions of the Celtic short-horn, were plentiful in No. 1, and a few teeth and bones were likewise met with in No. 2, whilst the proximal third of a right metatarsal, presenting a more recent appearance than the generality of remains from No. 3 deposit, was found in the latter.

Some of the long bones from No. 1 appear to have been split longitudinally, and give evidence of having sustained violent blows. One fragment of a vertebra from No. 2 bears traces of having been divided by a sharp instrument; moreover, it has the appearance of recent bones, and consequently may have been introduced by the fox.

The chisel (Plate XIII., fig. 4), is evidently portion of the distal end of a metacarpal or metatarsal of ox.

The following is a summary of the exuviæ of this ruminant :—

—	No. 1.	No. 2.	No. 3.	Debris thrown out of cave.
Teeth,	11	3	.	2
Mandible,	1	1	.	1
Vertebræ,	2	1	.	.
Scapula,	1	.	.	.
Humerus,	5	.	.	.
Radius,	2	.	.	.
Ulna,	1	.	.	.
Carpus,	1	.	.	.
Os Innominatum,	1	.	.	.
Femur,	1	.	.	.
Tibia,	6	.	.	.
Tarsus,	9	.	.	.
Metacarpal or Metatarsal,	13	.	1	.
Phalanges,	17	2	.	.
Fragments, long bones,	3	.	.	.
	74	7	1	3

GOAT (*Capra hircus*). SHEEP (*Ovis aries*)?

Numerous long bones, chiefly belonging to the feet, were plentiful in No. 1, but only a few turned up in No. 2. All were referable to a small goat or sheep, and were generally associated with the bovine remains of No. 1. Their fresh appearance in not a few instances in the last-named deposit betokened a recent introduction. Some of the metacarpals and metatarsals were very slender and cervine in appearance, and not larger than those of the roebuck, which has not been hitherto recorded from Irish deposits.

The bone implement (Plate XIII., fig. 2), was evidently fashioned from the metatarsal of a small goat or sheep. As regards dimensions the bones are in accord with Capra rather than Ovis. The diagnosis, however, is uncertain. The distribution of the remains is as follows :—

—	No. 1.	No. 2.	Debris thrown out of cave.
Teeth,	.	.	.
Cranium,	1	.	.
Mandible,	1	.	.
Vertebræ,	2	2	1
Scapula,	3	.	1
Humerus,	17	.	1
Radius,	11	.	.
Ulna,	1	.	1
Carpus,	.	1	.
Ribs,	.	1	.
Os Innominatum,	.	.	1
Tibia,	7	.	.
Tarsus,	5	.	3
Metacarpal or Metatarsal,	25	1	1
Phalanges,	7	.	.
Fragments long bones,	.	.	1
	80	5	10

Red Deer (*Cervus elaphus*).
Rein Deer (*C. Tarandus?*)

Numerous bones, referable to the red deer, were found from the base of No. 4 the stalamitic shelf upwards, increasing in numbers towards No. 2, where they were plentiful, but less so in No. 1. The molars presented the usual characters of the red deer, and the slender metacarpus and metatarsus, with their deep, narrow grooves, seemed to indicate that they belonged to that species. A portion of a metatarsus (No. 64), of the cervine type, a good deal stouter in proportion than the red deer's, and from No. 4, also a fragment of the distal end of a left humerus from No. 2 (No. 381) might be doubtfully claimed for the reindeer, but the absence of any portion of the antlers and teeth make it difficult to speak with certainty to the specific character of many of the cervine remains.

In the upper portions of No. 1 the bones, as usual, were yellow, and present a far more recent character than from No. 2; dendritic markings, however, were also on a few specimens from No. 1, but the latter, like the bones of man and the Irish elk from this deposit, may have come from No. 2 for the reason stated at p. 196.

The young and apparently uterine individuals were represented, and a few of the long bones had been split longitudinally, like the Irish elk's, with which they were associated. As I have generally noticed in numerous instances of horns and bones of the red deer from turbaries and river silt of Ireland that none indicated large individuals, as compared with similar remains from Great Britain; indeed, the Irish red deer seems to have been a small race, with more slender but elegantly branched antlers.

The following is an analysis of the cervine remains from the cave in question:—

	No. 1.	No. 2.	No. 3.	No. 4.	Crevices.	Debris thrown out of cave.
Teeth,	1	2	.	2	.	.
Cranium, Mandible,	1	1	.	.	.	.
Vertebræ,	4	5	.	.	1	.
Ribs,	.	4	.	.	2	1
Scapula,	.	2	.	.	.	.
Humerus,	1	1	.	.	1	1
Radius,	1	.	.	.	.	.
Ulna,	1	.	.	.	.	.
Carpus,	1	2	.	.	.	1
Metacarpus,	.	1	.	.	.	.
Metacarpus or Metatarsus,	.	3	.	.	1	.
Pelvis,	1	.	.	.	.	.
Femur,	2	2	.	.	.	.
Tibia,	.	.	.	.	1	.
Patella,	1	.	.	.	.	.
Tarsus,	3	.	.	.	.	.
Metatarsus,	3	2	.	1	.	.
Phalanges,	.	2	1	1	1	.
Cervine,	.	18	.	.	1	1
	20	45	1	4	8	4

Irish Elk (*Cervus megaceros*).

With the exception of the hare and rabbit, by far the greatest number of animal remains are referable to this ruminant.

The most noticeable and interesting features in connexion with its exuviæ are—

1st. The fractured state of the bones (Plate XIV., figs. 7 and 7A).

2nd. Evidences of gnawing by large carnivora (Plate XIV., fig. 8).

3rd. The discovery of human remains and implements fashioned by man associated with the broken bones of this deer and other mammals (Plate XIII., figs. 10 and 11).

With reference to the solutions of continuity, the remarkable feature is the number of long bones split longitudinally, with evidences of violent blows* of percussion, as evidenced by longitudinal fractures in such as the femur, tibia, and humerus; for there is not a long bone of the Irish elk which has not been split lengthways, or reduced to angular splinters. To have accomplished this, great force was required, and that force must have been exerted along the long axis of the shaft. The absence of the lion and hyena, leaving the bear and wolf as the only large members of the order hitherto identified from Irish deposits, renders it unlikely that they could have split the long bones so regularly. The few small cuspidated premolars of the bear, coupled with the succeeding broad crowns of the molars, are not suited for that continuous penetration and pressure along a surface for which the narrow crowns of the teeth of the felidæ and hyena, are so eminently adapted. As regards the wolf, it may be fairly doubted if that animal possessed the requisite strength of jaw for the accomplishment of such a feat, at all events, as regards the femur, humerus, and tibia.

Taking, therefore, into consideration the oblong and rounded stones, battered and chipped at their ends by blows, also other stone tools bearing traces of man's handiwork, and strewn about among the Irish elk's remains, one can scarcely doubt but that the regularity in the mode of fracture was the result of his ingenuity for the extraction of the marrow, and possibly also for other objects.

The following is a table of the bones of the Irish elk, with the beds in which they were found. Many pieces of shafts of long bones and other portions of the skeleton are indistinguishable in their fragmentary states from similar remains of other large ruminants. Besides, not a few were discovered among the material after removal, having been overlooked during the excavations.

* The bones of the Irish elk and other mammals, when recovered from subturbary deposits and exposed to the air, are apt to crack in the direction of the long axes, but the "sun-cracks" rarely penetrate the entire thickness or extend throughout the entire length of the bone, nor is there the splintering into fragments which the above exhibit generally.

The following is a Summary, omitting the more doubtful Pieces and Fragments of the remains of *C. megaceros* :—

—	Right or Left.	No. 1.	No. 2.	No. 3.	Crevices.	Debris thrown out of cave.
Cranium (Maxilla),	1 L.	·	1	·	·	*
Antler,	·	2	15	·	1	4
Cervical Vertebra,	·	·	1	·	1	·
Dorsal do.	·	·	3	·	·	·
Lumbar do.	·	·	1	·	·	·
Vertebral Fragments,	·	8	1	·	2	·
Ribs,	·	·	·	·	·	1
Scapula,	·	·	1	·	·	·
Head or Shaft of Humerus,	·	1	5	·	·	·
Trochlea of Humerus,	1 R, 5 L.	1†	4	·	1	·
Radius,	1 R.	2	5	·	·	·
Ulna,	1 L.	1	1	·	·	·
Semilunar,	·	·	1	·	1	·
Magnum,	·	·	1	·	·	·
Unciform,	1 L.	1	·	·	·	·
Metacarpal,	·	5	1	·	1	·
Acetabulum,	1 R.	·	1	·	·	·
Ischium,	·	·	·	·	2	1
Femur,	2 L.	1	2	·	·	·
Tibia,	3 R, 2 L.	2	5	·	·	1
Astragalus,	1 R, 1 L.	·	·	1	1	·
Calcaneum,	2 R, 2 L.	·	2	·	2	·
Navicular Cuboid,	·	·	1	·	1	·
Metatarsal,	·	3	3	·	1	·
Metatarsal or Metacarpal (?)	·	4	15	·	5	1
Proximal Phalanx,	·	2	4	·	3	1
Middle do.	·	·	·	·	1	1
Ungual do.	·	·	1	·	·	·
Fragments of long bones,	·	·	47	·	10	12
	·	33	122	1	33	22

THE GRISLY BEAR (*Ursus ferox*, Race *spelæus*).

Remains of bears were met with in the lower portion of (No. 4) the stalagmitic shelf, close upon the gravel (No. 5). They were also found in the sandy earth (No. 3), among the blocks of stalagmite, also in No. 2, whilst a metatarsal is recorded from No. 1.‡

* The more fragmentary specimens—to wit, pieces and morsels of long bones, &c., must be admitted as doubtful. Their claims to belong to the Irish Elk rest mainly on size and external aspects. The latter refer to the blackened exterior and dendritic markings. The majority displayed well-pointed indications of great violence and solutions of continuity in the direction of their long axes. Of course the stratigraphical position of relics discovered subsequently in the debris thrown out of the cave must be uncertain.

† Five left trochleas show that at least five individuals are represented by the relics.

‡ The dark external aspect of this bone (metatarsal) makes it uncertain whether it should be placed rather with the remains of No. 2.

The following elements of the skeleton have been identified:—

Summary.

—	Right.	Left.	Strata. 1.	2.	3.	4.	Crevices.	Debris thrown out of cave.
Teeth (Canine),	.	.	.	1	.	.	.	.
Mandible,	1	1	.	.	.	1	.	.
Vertebræ,	.	.	.	.	18	3	.	.
Ribs,	.	.	.	.	7	14	3	.
Scapula,	1	1	.	1	1	.	.	.
Humerus,	1	2	.	.	3	1	.	.
Ulna,	1	1	.	.	1	1	.	.
Scapho-lunar,	1	.	.	.	1	.	.	.
Trapezium,	1	.	.	.	1	.	.	.
Pisiform,	.	1	.	.	1	.	.	.
Metacarpal,	.	.	.	2	1	3	1	.
Acetabulum,	.	.	.	.	1	1	.	.
Tibia,	1	.	.	.	.	1	.	.
Fibula,	.	.	.	.	1	.	.	.
Astragal,	1	1	.	.	.	2	1	.
Calcaneum,	1	1	.	.	.	2	.	.
Navicular,	1	.	.	.	.	1	.	.
Cuboid,	1	.	.	.	.	1	.	.
Metatarsal,	.	.	1*	1	2	3	.	.
Metatarsal or Metacarpal,	.	.	.	.	.	2	.	.
Phalanges,	.	.	.	1	3	7	1	2
Fragments of long Bones,	.	.	.	.	2	.	.	.
Os penis,	.	.	.	1	.	.	.	.
	.	.	1	7	43	43	6	2

It is worthy of especial notice that the ursine remains from No. 3 were of the same mineral condition and outer coloration as those from No. 4—to wit, the broken right ulna (Nos. 121 and 122) and the fragments of a left humerus (Nos. 123 to 125), which were found in No. 3, and the fractured left ulna (Nos. 47, 49, and 50) and the pieces of a right humerus (Nos. 4, 5, and 6) from No. 4 deposit. Now, whilst the bones met with among the detached blocks of stalagmite of No. 3 were fractured by violence, the others in No. 4, the stalagmitic shelf, were more or less entire. No doubt, all belonged to an individual or individuals which had originally left their bones in No. 4 until a portion of the latter was broken up, when they participated in the injuries to which the stalagmitic shelf was subjected.

The bears' remains clearly show the presence of at least two individuals. The only parts, however, available for specific determination are the molars. The mandibles and bones clearly show that their owners were of large dimensions, and equalled the *Ursus spelæus* in size. This will be apparent from the bones and teeth represented on Plate XIV.—to wit, the left pisiform, fig. 5, left astragal, and navicular, figs. 3 and 2, and the ungual phalanx, fig. 4.

The os penis, fig. 6, has been compared by Dr. Carte with that of *U. maritimus*,

* Stratigraphical position doubtful, possibly from No. 2.

and by Professor Flower with the same bones in *U. maritimus, ferox, ornatus,* and *Americanus,* all of which are curved; whereas, fig. 6 is straight, and the same, Dr Flower states, is observed in the os penis of a young *U. arctos* in the museum of the Royal College of Surgeons. The bone, however, is not entire, having lost portions of the proximal and distal extremities. Its length is 5 inches, and maximum girth 1·5 inches.

The left ramus of the mandible has lost the condyle, and the diasteme was recently injured, but the four molars and canine were in place; the former are shown in Plate XIV., figs. 1 and 1A. The teeth show a full grown bear, with their surfaces scarcely marked by wear, and presenting the porcine character. The following are their dimensions:—

Mandible.	Length. (a. p. d.)	Length. (a. p. d.)	Breadth.	Breadth.
Fourth Premolar,	13· millimetres	·51 inch	9· millimetres	·32 inch
First Molar,	27· "	1·5 "	13· "	·54 "
Second Molar,	30· "	1·13 "	16· "	·72 "
Third Molar,	24· "	·98 "	18. "	·71 "

The fourth premolar has a simple conical crown, without any flanking tubercles.

As regards size, this tooth is as large as the premolar of the cave bear.* The same may be said of the three molars. The second and last are equal to many of the largest penultimate and ultimate molars of the great cavern bear.

The teeth far exceed the dimensions of the *U. arctos,* and are larger than any belonging to the recent *U. ferox,* that have come under my notice; indeed, as regards size, both bones and teeth generally compare favourably with the largest ursine remains found in Irish strata.

The contour of the crown of the last molar is more quadrangular than usually seen in that of *Ursus arctos.*

Several entire bones of the foot were found in juxtaposition in the stalagmitic floor, such as the right calcaneum (No. 46) and astragal, Plate XIV., fig. 3. The latter shows a circular-shaped navicular facet for fig. 2; also a cuboid (No. 19), and the left calcaneum (No. 45), were found close to a left astragal (No. 43).

Individual and race characters greatly affect the external appearance and endo skeletons of *Ursus arctos* and *U. ferox*; for example, the isabelline variety of *U. arctos* from the snow-clad ranges of Central Asia, and the dark brown or black races of Europe, are so pronounced, not only as regards the colour of the pelage, but also the teeth, that as far as differences are concerned, had they been found in fossil states, one could scarcely blame him who pronounced their remains to have belonged to different species.

* The single conical crown, although general in *Ursus arctos,* may be present, according to Busk, in the fourth premolar of *U. ferox,* both living and fossil.

As to size and dimensions of teeth, neither in the case of the largest grisly and brown bears are the bones and teeth so large as the generality of the so-called *Ursus ferox fossilis* and *U. spelæus.* Again, in these living and lost species the small distinctions referring to the contours and characters of certain teeth, as pointed out by Busk* seem to vary in individuals, whilst the appendicular skeleton offers no invariable points of distinction. The only bear now living, whose dental and skeletal characters and dimensions approach nearest to the extinct animal, is the *Ursus ferox*, which is probably the lineal descendant of the *Ursus fossilis* and *U. spelæus*; moreover, the two last-named may have been only small and large races or even individual or sexual states of one species.

From considerable field experience of the habits of the brown bear of Central Asia, and in comparing its morphology with the European brown bear, grisly bear, and the extinct cavern forms, I was struck, in the case of the first, with the modifications dependent on the struggle for existence. The teeth are relatively small, and more porcine on their crown surfaces than appears to be the case in the carnivorous, grisly, and the European brown bears, for the reason that the Asiatic form, restricted to high mountain ranges, where it hibernates for upwards of five months, subsists entirely on roots, herbs, and fruits. It is timid, and unless under severe pressure, will rarely attack man, and it is not fleet enough to prey on the Alpine ungulates and other animals. The light colour of the fur consorts with that of the surrounding objects. Sometimes three premolars exist in the jaws of old individuals, and invariably the first and fourth premolars.

The grisly still preys on the bison, and no doubt the extinct forms enjoyed unlimited advantages with respect to animal food and freedom, and therefore would naturally attain to larger dimensions than the recent allied forms; whilst both would become larger and more ferocious than the herbivorous brown bear, or any species compelled to subsist altogether, like the Himalayan brown bear, on a vegetable diet.

As far, therefore, as dimensions are concerned, the bones and teeth found in Ballynamintra cave maintain the characters of all the other Irish ursine remains which, according to Busk, are referable to *Ursus ferox* of the Rocky Mountains of North America. It is my impression, however, that the modifications in the skeletal elements of all these so-called species are so slight, and subject to such variability, that they might fairly represent races of one typical form or species—to wit, the great cavern bear of the Pleistocene period.

The Badger (*Miles taxus*).

An entire skull (No. 493), with its mandible slightly blackened, and the crowns of the molars much detrited, was found in No. 2 deposit. This plantigrade is still not uncommon in the district.

* See Reports on Animals' Remains from Brixham and Gibraltar Caverns—"Phil. Trans." for 1863, p. 542. "Trans. Zool. Soc. London," vol. x., p. 53.

The Wolf (*Canis lupus*).

The old Irish wolf or stag hound, approached in size to the wolf; consequently, there is considerable difficulty in eliminating its remains from the latter. The second upper molar (No. 167) from No. 3, and humerus (No. 554), which was associated with bones of Irish elk and bear in a breccia of calc tufa contained in a crevice; also a proximal fragment (No. 372) of a femur, black and dendritic, from No. 2, might be referred to the wolf. The more trenchant and stouter cusps of the above-named molar seem to associate it rather with the latter. It was found at a depth of five feet, under the wall, close to a swallow hole, among pebbles.

The Fox (*Canis vulpes*).

This cavern hunter, like the rabbit, is so apt to leave its own remains, or the refuse of its food, among older relics of the superficial deposits as to make it difficult or impossible to eliminate the former from the latter. Upwards of fifty bones referable to the fox were discovered in No. 1, but only four in No. 2, and none in the deeper strata. A few showed the discoloration of the ancient bones, but the majority had a recent outward appearance.

The Dog (*Canis Hibernicus*?).

Thirteen fragments of bones and three molars of a large variety of Canis, equal and even taller than the wolf, were met with in No. 1. The mandibles indicated a large hound; the teeth were usually well worn and the jaws more slender than obtains ordinarily in the wolf, but especially pronounced in the large extinct Irish wolfhound.

The remains were frequently discoloured and blackened, and sometimes light yellow, and recent in appearance.

The Marten (*Martes sylvestris*).

The following remains of this weasel, still sparsely scattered over the more secluded parts of the island, were found in the upper portions of No. 2 and in No. 1 deposits. A right ramus of a mandible, with teeth in their sockets, but very fresh-looking, was derived from No. 2, whilst the distal end of a left femur was met with in No. 1, and a right femur and a left ramus of a mandible. The two latter were found at the distance of fourteen feet from the mouth of the cave; also fragments of two left maxillæ, with teeth, were discovered from eighteen to twenty-one feet inwards in No. 1. The majority of the remains were fresh-looking, and had little of the appearance of old bones.

The Hare (*Lepus variabilis*?).

The fact that the *Lepus timidus* has not been recognised as one of the recent mammals of Ireland, and that the remains found in Shandon cave with the mammoth bear and reindeer* appear to have belonged to the mountain hare, from the characters relating to the comparatively shorter long bones, which seemingly

* Adams, *Op. cit.*, vol. xxvi., p. 228.

obtain likewise in the case of the denizens of Ballynamintra cavern, lead me to believe that all belong to the *Lepus variabilis*. It is scarcely possible, however, to differentiate specific distinctions on detached bones, and, therefore, the confirmation of the remains from the deeper deposits must be for the present accepted as somewhat doubtful. Several bones strewn about in the lower portions of No. 2, and in the crevices of the walls, showed distinct dendritic markings, and were blackened or encrusted with stalagmite, but others in the same situation and associated with the other animal remains, contrasted with the former in their yellow and recent outer aspects.

It will be seen from the return that the largest quantities of remains of hare were found in No. 2 deposit. They were associated with the human bones and charcoal, and were not accompanied by rabbit remains. Probably the hare, like the ungulates, formed a staple article of food to the human denizens of the cave.

The Rabbit (*Lepus cuniculus*).

The remains of this species were for the most part confined to the upper horizon of No. 1. A few long bones and teeth were met with in No. 2, but none showed the dark discolorations of the hares' bones in these situations.

Hedgehog (*Erinaceus Europæus*).

A tibia of this insectivore was found in the lower horizon of No. 1, at a distance of eighteen feet, on the right side. It was light-coloured.

General Summary of the Mammalian Remains.

—	1.	2.	3.	4.	Crevices.	Debris thrown out of cave.	Totals.
Man,	19	12	1 ?	.	1	3	36
Horse,	4	. .	.	.	. .	.	4
Pig,	23	19	5	.	3	3	53
Ox,	74	7	1	.	. .	3	85
Goat or Sheep,	80	5	. .	. .	. .	10	95
Red Deer,	20	45	1	4	8	4	82
Irish Elk,	33	122	1	.	33	22	211
Grisly Bear,	1	7	43	43	6	2	102
Badger,	.	1	.	.	.	.	1
Wolf,	. .	1	1	.	1	.	3
Fox,	49	4	.	.	. .	.	53
Dog,	16	. .	.	.	.	.	16
Marten,	7	1	. .	.	.	.	8
Hare,	108	133	23	.	29	11	304
Rabbit,	165	8	1	.	1	3	178
Hedgehog,	1	.	.	.	.	.	1

Man,	36	Carnivora,	183
Insectivora,	1	Ungulata,	530
Rodentia,	482	Grand Total,	1,232

Birds—Amphibia and Invertebrates.

Long bones of birds were found in No. 2 and crevices of the wall. A few showed the dark colouring and dendritic markings of the more ancient exuviæ, and several were encrusted with stalagmite, whilst others had quite a recent aspect. They were met with also in No. 1, especially in its upper portion. Some of their appendicular elements indicated waders allied to herons, large sandpipers and small plovers, besides land birds of the size of the rook, pigeon, and smaller species. In No. 1 the pellets (?) of rapacious birds, possibly of owls, contained fragments of bones of frogs.

The *Invertebrata* were represented by a valve of a marine mussel (Mytilus), which with a limpet (Patella) lay close to stone rubbers, striking stones, and large lumps of charcoal, at a distance of eighteen to nineteen feet from the entrance and in the centre of No. 2 deposit. The land shells (Helix), found at a depth of six feet in No. 2, had in all probability crawled into the interior.

The time and labour bestowed on the explorations connected with Ballynamintra cave have been considerable, and much pains have been taken in determining the facts elicited by its deposits and exuviæ. As regards the latter, I feel bound to acknowledge the assistance I have received from my valued coadjutor, Mr. Ussher, who not only superintended the explorations, but has rendered me valuable aid in the cataloguing and classifying of more than 1,100 remains from this interesting bone cave.

Man.

Characters and Distribution of the Human Bones.

I have been enabled to determine with certainty about thirty-seven fragments belonging to at least two skeletons.

The following is a list of the specimens with their numbers and conditions as recorded in our catalogue, and also the deposit in which each bone was found :—

Nos. 747, 746. Right and left supra-orbital portions of a frontal, possibly belonging to one person. The supra-orbital ridges are prominent. They are discoloured (No. 1 ?), Plate XIV., fig. 9.

No. 749. Fragment of a left temporal, including the tympanic, mastoid, and part of the petrous portions. Discoloured (No. 1 ?).

Nos. 750, 751, 752. Fragments of parietal and occipital. Discoloured (No. 1 ?).

Nos. 753, 756. Fragment of a frontal. Discoloured (No. 1 ?).

Nos. 754, 755, 757. Ditto parietal showing a dark exterior with light brown dendritic markings. Thick central table (No. 1 ?).

No. 758. Supra-occipital with a thick squamous portion, the curved lines not sharply defined (No. 1 ?).

No. 759. Ex-occipital thin squamous portion and pronounced curved lines (No. 1 ?).

No. 204. Canine, somewhat worn on the crown (No. 2).

No. 762. First premolar lower, slightly touched by wear (No. 1 ?).

No. 761. Premolar, well worn, unevenly (No. 1).

No. 266. Nearly entire cervical vertebra, possibly third or fourth. Blackened (No. 2).
No. 760. Fragment of cervical vertebra. Light-coloured (No. 1).
No. 300. Left clavicle, distal end in two fragments yellow and coated with stalagmite (No. 2 ?).
No. 201. A nearly entire rib in stalagmite (No. 2).
No. 203. Left radius proximal half yellow and coated with stalagmite (No. 2).
No. 239. Left radius proximal half yellow and coated with stalagmite (No. 2).
No. 200. Left ulna proximal third coated with stalagmite (No. 2).
No. 221. Third metacarpal right black and coated with stalagmite (No. 2).
No. 267. Fifth metacarpal, left black (No. 2).
No. 68. Proximal phalanx fourth or fifth finger. Blackened (No. 3 ?).
No. 196. Proximal end of right femur, head wanting small relatively. Yellow (No. 2).
No. 197. Distal end of left fibula (No. 2). Yellow, coated with calc tufa).
No. 763. Right first metatarsal, distal half dark coloured, but not blackened (No. 1).
No. 764. Left first metatarsal, decomposed (No 1).
No. 706. Left third metatarsal. Light-coloured, decomposed (debris) ? No. 1.
No. 682. Left fourth metatarsal. Light-coloured (debris) ? No. 2 ? Bears traces of calc tufa.
No. 683. Left fifth metatarsal. Light-coloured (debris).
No. 748. Right fifth metatarsal, slightly blackened (No. 1 ?).
No. 525. Proximal phalanx, fourth metatarsal. Yellow, decomposed (crevice). No. 2 ?

Bear.

Characters and Distribution of the Bear Bones.

Nos. 1–3, 10, 11, 22. Fragments of ribs, light-coloured and porous, from stalagmite (No. 4).
Nos. 4–6, 13. Portions of a right humerus, extracted from blocks of solid stalagmite (No. 4), light-coloured.
No. 8. Metatarsal solid stalagmite (No. 4).
No. 9. Portion of a phalanx ? (No. 4), ditto.
Nos. 14–16. Neural spines vertebra (No. 4), ditto.
No. 19. Right cuboid (No. 4), ditto.
No. 23. Phalanx (No. 4), ditto.
No. 24. Do., second (No. 4), ditto.
No. 25. Third metacarpal or metatarsal ? (No. 4), ditto.
No. 26. Fifth Do. or do. ? (No. 4), ditto.
No. 27. First metacarpal (No. 4), ditto—length, 4 inches.
No. 28. Third metatarsal (No. 4), ditto.
Nos. 29, 30. Third metacarpal, distal end (No. 4), ditto.
No. 32. Distal end of a right fibula (No. 4), dark coloured.
No. 38. Phalanx, light-coloured (No. 4), stalagmite.
No. 40. Metacarpal left first, $3{\cdot}2 \times 1{\cdot}1$ inches (No. 4), ditto.
No. 42. Right navicular, $2 \times 1{\cdot}65$ in height (No. 4), ditto.
No. 43. Left astragal, $2{\cdot}17$ (*a.p.d.*) $\times 2{\cdot}5$ (No. 4), ditto. Plate XIV., fig. 2.
No. 44. Right astragal, smaller than 43, but fits navicular 42; $2{\cdot}09$ (*a.p.d.*) $\times 2{\cdot}37$ (No. 4), ditto. Plate XIV., fig. 3.
No. 45. Left calcaneum fits to left astragal 43 (No. 4), ditto.
No. 46. Right calcaneum in matrix, $2{\cdot}52 \times 4{\cdot}1$ fits nearly to 44 (No. 4), ditto.
Nos. 47, 49, 50. Fragments of a left ulna, $4\frac{1}{2} \times 2\frac{1}{2}$ (No. 4), ditto.
No. 48. Right tibia, proximal portion (No. 4), ditto.
Nos. 51, 20. Portions of right tibia, shaft (No. 4), ditto.

No. 52. Portion of acetabulum, left side, with ischium also (No. 4), ditto, but dark-coloured stalagmite.

Nos. 53–55. Left ramus mandible, with second molar in place; detached fragment, with canine in place (54), and detached first true molar (55).

Nos. 59–62, 56–58. Right ramus mandible, same bear as (53), with incisor teeth of ditto (56 to 58); outer incisor of 59 represented by 60; fourth premolar of 59 by No. 61; first, second and third molars of 59 represented by No. 62; now replaced in jaw (No. 4), ditto. Plate XIV., figs. 1 & 1A.

No. 65. Vertebra (lumbar?) (No. 4), ditto.

No. 74. Portion of left acetabulum, with ileum; left side, possibly same side of 52 (No. 3), light coloured.

No. 75. Fragment of centrum of vertebra of bear? (No. 3), ditto.

Nos. 76, 77. Fragments, proximal end of a humerus of bear? (No. 3), ditto.

No. 78. Rib fragment of bear? (No. 3), ditto.

No. 92. Fourth metatarsal, light-coloured (Nos. 3 or 4? probably No. 3).

Nos. 94–101. Fragments of ribs (Nos. 3 or 4, probably No. 3).

No. 109. Second rib, at 8 ft. in the interior, and 4 ft. from east wall, in pale, gritty earth, under and between the stalagmite blocks (No. 3).

Nos. 110, 111. First rib (110), ditto, ditto; possibly same individual as foregoing five, 94 to 109 (No. 3).

No. 115. Phalanx (No. 3), ditto.

Nos. 121, 122. Right ulna, light-coloured (No. 3).

Nos. 123, 124, 125. Shaft fragments and distal end of left humerus (No. 3), ditto.

Nos. 126, 127. Portion of right scapula, possibly fellow of 315 (No. 3), ditto.

No. 129. Scapho-lunare, right (No. 3), ditto.

No. 130. Trapezium, right (No. 3), ditto.

No. 131. Second left metatarsal (No. 3), ditto.

No. 132. Third left metatarsal (No. 3), ditto.

No. 133. Pisiform, left—length, 2·4 inches (very large)— (No. 3), ditto. Plate XIV., fig. 5.

No. 134. Distal end of a metacarpal? (No. 3), ditto.

Nos. 135, 136. Phalanges, proximal (No. 3), ditto.

Nos. 137–151. Fragments of vertebræ (No. 3), ditto.

Nos. 152–154. Portions of ribs (No. 3), ditto.

No. 168. Fragment of humerus (small), No. 3.

No. 198. Fragment of metacarpal bear? (No. 2), encrusted with stalagmite.

No. 220. Fragment of fibula (No. 2), encrusted with stalagmite.

No. 256. Fragment of rib, blackened (No. ?)*

No. 257. Third metacarpal.*

No. 271. Fourth metatarsal, very black (No. 2).

No. 272. Fifth, left, metacarpal, light-coloured (No. 2).

No. 273. First metacarpal, ditto (No. 2).

No. 315. Left scapula, mutilated, blackened and dendritic (No. 2).

No. 316. Os penis, blackened and dendritic (No. 2). Plate XIV., fig. 6.

No. 495. Eight fragments of long bones, light-coloured, like the others, from the stalagmite (Nos. 3 or 4?).

No. 526. Proximal phalanx, blackened (crevice).

No. 545. Right astragal, encrusted with hard white stalagmite (crevice).

No. 555. Fragment of rib, blackened or encrusted with stalagmite (crevice).

No. 596. Canine, mutilated, black and dendritic (No. 2).

No. 627. Proximal phalanx, ditto ditto, (No. 2).

No. 680. Proximal phalanx, light-coloured (debris).

No. 681. Distal phalanx—length, 2 inches—light-coloured (debris).

No. 1081. Metatarsal, blackened (No. 1).

* Nos. 256 and 257 were found in a crevice with the knife handle. Plate XIII., figs. 1 and 1A.

Irish Elk.

Character and Distribution of the Irish Elk Bones.

No. of Register.	No. of Fragments.	
63	1	Left astragal in No. 3, light-coloured.
169	1	Olecronon process left ulna, dark colour, found 23 feet inwards on east side in a hollow of stalagmite floor, which here approaches the roof in No. 2 ?
170	1	Fragment of upper jaw left, also dark-coloured with a piece of charcoal, sticking in a crack on the bone, from No. 2 ?
205	1	Portion of lower dorsal vertebra, very black and dendritic, from No. 2.
274	1	Portion of palm of antler, $8\frac{1}{2}$ inches by 4 inches in width, with dendritic markings, from No 2.
275	1	Distal end of metacarpal cleft down the middle, from No. 2.
276	1	Fragment of a shaft of femur (No. 2), dendritic marks.
277	1	Fragment of a right acetabulum (No. 2), dendritic marks.
278	1	Ditto long bone (No. 2), dendritic marks.
279	1	Ditto palm of antler (No. 2), black and reddish.
280	1	Ditto palm of antler (No. 2), with dendritic marks.
281	1	Right tibia, distal end, with a long splinter detached, showing evidence of violence (No. 2). Plate XIV., figs. 7 and 7A.
286, 287	2	Portion of palm of antler, $7\frac{1}{2} \times 3\frac{1}{2}$ in width, with dendritic marks, No. 2.
288	1	Semilunar left, showing dendritic marks (No. 2), on the west side, close to the wall, under a projecting portion.
289	1	Fragment cervical vertebra, very black and dendritic (No. 2).
290, 292–295	5	Splinters of long bones split lengthways, also discoloured (No. 3).
291	1	Radius fragment proximal end, also dendritic (No. 2).
306–314	9	Splinters of long bones, dark-coloured and dendritic, some split lengthways were found in a crevice with No. XXIX. stone implement, showing perforations. These lay under a shelf of the western wall, among black earth and fragments of limestone and pebbles (No. 2). The bones are doubtfully referred to the Irish Elk.
317	1	Fragment of a humerus, blackened and dendritic (No. 2).
319	1	Centrum dorsal vertebra, black and dendritic (No. 2).
320	1	Ungual phalanx, ditto ditto (No. 2).
321	1	First phalanx, ditto ditto (No. 2).
322	4	Distal end left humerus, showing evidence of gnawing on the articulating surface, black and dendritic (No. 2), Plate XIV., fig. 8.
323	1	Right calcaneum, gnawed ? dark and dendritic (No. 2).
324	1	Distal end of left tibia smashed by violence, dark and dendritic (No. 2).
325, 327, 328, 331, 334	7	Fragments of a metacarpal or metatarsal, and split lengthways, dark-coloured and dendritic (No. 2).
326, 333, 334	2	Fragments of metatarsal, split lengthways into 8 pieces (No. 2). Ditto metacarpal, ditto ditto (No. 2), dark and dendritic.
335–340	6	Fragments of long bones, split lengthways, black and dendritic, No. 2.
348, 349	2	Fragments of palm of antler, black and dendritic (No. 2).
357	1	Phalanx proximal right, black and dendritic (No. 2).
383, 385–389	6	Fragments of metacarpals or metatarsals, split lengthways, black and dendritic (No. 2).
384	1	Fragment of humerus, black and dendritic (No. 2).
390, 399	2	Fragments, long bones, ditto ditto (No. 2).

No. of Register.	No. of Fragments.	
400, 401	2	Portion shaft of metatarsal, black and dendritic (No. 2).
402	1	Ditto metacarpal, ditto ditto (No. 2).
403	1	Ditto metacarpal or metatarsal, black and dendritic (No. 2).
405	1	Fragment of tibia, left, ditto ditto (No. 2).
406	1	Portion of femur left, split lengthways, ditto ditto (No. 2).
408	1	Fragment of vertebra, ditto ditto (No. 2),
409	1	Greater tuberosity of humerus, ditto ditto (No. 2).
410, 411	2	Fragments of long bones, ditto ditto (No. 2).
412, 413	2	Fragments of antler, palm and snag, ditto ditto (No. 2).
414	1	Ditto long bone, ditto ditto (No. 2).
415, 416, 450	3	Portions of a beam of antler, much decomposed, gnawed? No. 450 is black and dendritic, No. 2.
404, 431	2	Fragments of tibia, black and dendritic, No. 2.
443	1	Distal end tibia, black and dendritic (No. 2).
444–446	3	Splinters of long bones, split lengthways, black and dendritic (No. 2).
455	9	Fragments of bone and antler, black and dendritic (No. 2).
464	1	Fragment of antler, black and dendritic (No. 2).
477	1	Fragment of beam antler, with surfaces worn off (No. 2).
496	1	Proximal phalanx, black and dendritic (No. 2?), found in soil under the GREENSTONE CELT. Plate XIII., fig. 5.
497, 498	2	One fragment of left and 1 of right distal ends of humerii, gnawed? Black and dendritic, also found with 496 in soil under the CELT (No. 2?).
499	1	Lumbar vertebra, black and dendritic, found in soil under the CELT (2?).
508	1	Fragment of antler, black and dendritic, from a crevice.
513	1	Navicular cuboid, black, and encrusted with earth and fragments of limestone in a crevice in the west wall, filled with dark soil.
514	1	Half of distal articulation of metacarpal or metatarsal from same situation as 513.
515	1	Proximal phalanx, pale-coloured, and free from dendritic marks, from the same situation.
530	1	Distal end left humerus, violently split lengthways, gnawed, black, with dendritic marks, from a crevice in west wall, 4 feet below the surface of No. 1.
531	1	Left calcaneum, gnawed? blackened, with dendritic marks, from same situation as 530.
532	1	Semilunar, dark-coloured at one end, from same situation as 530.
533–538	6	Splinters of long bones? Irish elk, excepting 537, fragment of a metacarpal or metatarsal, and 538, which is a fragment of an axis, and is white and abraded; these are dark-coloured and dendritic, from same horizon as preceding.
546	1	Proximal phalanx, black and dendritic, and encrusted with hard stalagmite, behind a portion of the west wall, which had fallen down.
547	1	Fragment of centrum of vertebra of large animal, Irish elk? porous, and encrusted with stalagmite; same situation.
548, 549	1	Fragments of lower ischial arch, porous, and encrusted with stalagmite; same situation with the foregoing. These were associated with a right astragal, No. 545, of bear and bits of charcoal.
556	1	Metacarpal, encrusted with calcareous deposit, from a crevice.
559	1	Penultimate phalanx, black and dendritic; situation uncertain, possibly from crevice in wall.
560	1	Right astragal, black and dendritic; situation uncertain, possibly from crevice in west wall.
562, 563	2	Splinters of long bones, black and dendritic, from a crevice in west wall, on a level with the lower horizon of No. 2.
567	1	Fragment of a metacarpal or metatarsal (crevice), black and dendritic.

No. of Register.	No. of Fragments.	
570	1	Fragment of proximal phalanx, black and dendritic (crevice).
571	1	Ditto of calcaneum, right, with surface abraded (crevice).
573	1	Ditto of metatarsal, gnawed? black and dendritic (crevice).
582	1	Proximal phalanx, black and dendritic.
583	1	Splinter long bone, ditto and ditto. Nos. 582, 583, were found deep in No. 2 or in No. 3, under and between huge blocks of stalagmite (No. 2).
585	1	Splinter long bone, black and dendritic (No. 2).
586	2	Fragment of a magnum, ditto, ditto (No. 2).
597	2	Fragments of long bone (No. 2).
598	1	Fragment of a navicular cuboid, blackened and dendritic (No. 2).
599	1	Glenoid cavity of scapula, black and dendritic (No. 2).
601	1	Left calcaneum, blackened and dendritic (No. 2).
602	1	Left distal end humerus, ditto, ditto, gnawed (No. 2).
603	1	Left distal end radius, left, ditto, ditto, ditto (No. 2).
604	1	Centrum dorsal vertebra, ditto, ditto (No. 2).
605–604	8	Fragments of long bones, ditto, ditto, No. 605, humerus? (No. 2, upper portion).
609	1	Proximal end left radius, ditto, ditto (No. 2, upper portion).
610–613, 615–616	6	Fragments of long bones, ditto, ditto (No. 2, upper portion).
614	1	Proximal end of radius? ditto, ditto (No. 2, upper portion).
617	1	Fragment of humerus, ditto, ditto (No. 2, upper portion).
619, 618, 620, 621, 623, 625, 626	7	Fragments of long bones, ditto, ditto (No. 2, upper portion).
622	1	Distal end of left radius, ditto, ditto (No. 2, upper portion).
628	1	Fragment of distal articular process of humerus (No. 2, upper portion).
641	1	Distal end right tibia, blackened and dendritic; uncertain position, found among the debris thrown out of the cave subsequently.
642, 647	12	Phalanges (penultimate and proximal), blackened and dendritic; position uncertain, among the debris of the cave.
643	1	Fragment distal end metacarpal or metatarsal; position uncertain, among debris, blackened and dendritic.
644, 646, 648–654, 656, 658, 659, 661	13	Fragments of long bones, blackened and dendritic, among the ejected debris.
655	1	Fragment of antler, blackened and dendritic, among ejected debris, among debris.
657	1	Fragment of beam of antler, gnawed, surface denuded, among debris.
660	1	Fragment of oblurater foramen, black and dendritic, debris.
663	1	Fragment of rib, ditto ditto debris.
715	1	Centrum of vertebra, blackened and dendritic (No. 1 ?).
716	1	Distal end right tibia, ditto ditto (No. 1 ?).
717	1	Proximal phalanx, ditto ditto (No. 1 ?).
718	1	Ditto ditto (smaller), ditto ditto (No. 1 ?).
719	1	Metatarsus, ditto ditto (No. 1 ?).
720	1	Ditto, portion of, ditto ditto (No. 1 ?).
721	1	Radius, portion of right ditto, ditto (No. 1 ?).
722	1	Femur, portion of left shaft, blackened and dendritic, (No. 1 ?).
723	1	Tibia, portion of left shaft, ditto (No. 1 ?).

No. of Register.	No. of Fragments.	
725	1	Radius, portion of proximal end, blackened and dendritic, (No. 1 ?).
724, 726, 727, 732	4	Fragments of metacarpals and metatarsals, ditto (No. 1 ?).
730	1	Fragment ulna ? ditto (No. 1 ?).
731	1	Fragment humerus ditto (No. 1 ?).
733	1	Fragment distal end humerus, ditto (No. 1 ?).
734, 735	2	Fragments of antler, blackened and dendritic (No. 1 ?).
737, 738	2	Fragments of metacarpal or metatarsal, blackened and dendritic (No. 1 ?).
739–744	6	Fragments of vertebræ, blackened and dendritic. (No. 744 spine) (No. 1 ?).
745	1	Left unciform, blackened and dendritic (No. 1 ?).
889	1	Fragment of centrum of vertebra, blackened and dendritic (No. 1 ?).
902	1	Fragment metacarpal or metatarsal, blackened and dendritic (No. 1, lower horizon).
906, 907	2	Fragments of palm of antler, blackened and dendritic (No. 1 or No. 2).
918	1	Fragment of centrum of vertebra, blackened and dendritic, in recess of a crevice.
919–920	1	Fragments of long bones, blackened and dendritic, from recess of crevice.
925	1	Fragment of metatarsal, blackened and dendritic (No. 1).
927	1	Fragment of a radius (No. 1).
929, 917	1	Metacarpal or metatarsal (two portions, same bone ?), blackened and dendritic (No. 1 ? a crevice, to the right), blackened and dendritic.
930	1	Fragment of long bone, blackened and dendritic, in same crevice with Nos. 929 and 917.
1176	1	Fragment of a metacarpal or metatarsal (No. 1 ?).

V.—Description of the Implements. By R. J. Ussher.

Bone Implements, Amber, Pottery.

1. Amber bead (Plate XIII., figs. 8 and 8A). Diameter, ·8 inch; thickness varying from ·25 to ·325 inch; pierced by a hole ·25 inch diameter, not placed exactly in the centre of the bead; colour, deep and reddish. The amber is inclined to disintegrate into granular bits. Found 13th May, 1879, in the brown earth, under shelving wall to the right, 7 feet outside the entrance.

2. Hand-made pottery (Plate XIII., figs. 7 and 7A). Fragment of the rim of a vessel that, judging by the curve, measured 11 inches in diameter. Indentations as if made by the finger-nail on the rim. Lip slightly projecting. Thickness not uniform. Concave or internal side charred. Found 12th May, 1879, in debris composed of the two upper strata.

3. Pointed bone instrument (Plate XIII., fig. 2). Length, 3·1 inch; colour, yellowish; not brittle. Formed from the proximal half of the metatarsal of a goat, or other small ruminant, ending in an irregular point that bears traces of wear. Similar instruments may be seen in the Museum of the Royal Irish Academy. Found April, 1879, in the grey earth, with bones of Irish elk, deer, pig, goat, and hare.

4. Squared, carved knife-handle, 2 portions (Plate XIII., figs. 1 and 1A). Colour, yellowish; very brittle. The two pieces when placed together are 2·55 inches long, ·9 inch in breadth, and ·7 inch in thickness, having formed part of a longer instrument from which they had been broken off. The corners are rounded, and the four faces are carved with concentric circles, apparently by metal tools. In the centre is a cavity, opening to the end of the instrument, stained internally of a ferruginous colour, and seems to have held an iron blade. This knife-handle is considered by Mr. John Evans, F.R.S., to belong probably to what in England is known as the Saxon Period, and not to be more ancient than the 6th or 7th century. Knife-handles similarly ornamented with concentric circles occur in the Museum of the Royal Irish Academy. Case 4 contains such a bone knife-handle, No. 358 with a bronze (?) blade, No. 1,464 is another similar handle. Found 19th May, 1879, in a recess of the left wall, against which lay an undisturbed block of stalagmite, but water-worn fissures that lead down to this recess and below it, from the horizon of the brown earth, showed that it was in a line of drainage. Associated in the same recess in earth was the rude celt, No. XXVIII., and bones of bear and pig.

5. Bone implement (Plate XIII., fig. 3), possibly the broken shaft of an arrow or harpoon. Colour, pale brown; length, 4·25 inches; thickness, from ·45 to ·22 inch. Consists of a straight, rounded shaft, flattish on the opposite sides, broken or blunted at the thicker end, whence it diminishes towards the other end, which has a carved, pointed barb or prong projecting from it obliquely, the base of this prong being cut into as if by string. Beyond this prong the shaft is broken off, and another prong corresponding to the former appears to have been broken off the opposite side of the shaft. None of the original surface of the bone remains. Found 20th May, 1879, 14 feet from the entrance by the left wall in the lower part of the brown earth.

6. Chisel-shaped bone implement (Plate XIII., fig. 4). Colour, yellowish; traces of calc tufa adhering; not brittle; length, 4·8 inches. Formed from half of the distal portion of the metatarsus of a ruminant (probably ox), cleft down the middle, the distal extremity serving as a handle blurred as if by blows, and the point ground down to an edge on both sides. Found in April, 1879, in a crevice of the right wall about 8 feet from the entrance. This chink separated from the rest of the rock a huge mass of limestone that, on being undermined, fell down and disclosed the chisel.

7. Portion of pointed bone implement (Plate XIII., fig. 6), broken across, flattish, rounded, like the point of a netting-needle. Length, 1·75 inch; breadth, ·6 inch; thickness, ·22 inch; colour, yellowish. Found, April, 1879, either in the brown earth or in the grey earth.

8. Carved bone, probably a clasp for clothing (Plate XIII., fig. 9), formed from the

metatarsus of a small deer or goat, both ends having been pared off, a conical hole cut in the distal end, and another hole cut transversely through the shaft with some sharp instrument; colour, yellowish; not brittle; length, 2·6 inches. Found, 20th May, 1879, about fourteen feet from the entrance, in the brown earth.

Stone Implements.

9. Polished Celt (Plate XIII., fig. 5), flattened at the sides, approaching the triangular form, which Mr. Robert Day, F.S.A., of Cork, the well-known Irish Antiquary, states to be an unusual form of Irish Celt, very symmetrically wrought, of dark greenish stone;* length, 4·3 inches; greatest breadth, 2·6 inches; greatest thickness, ·85 inch. This is the only polished stone implement met with in the cave. Found, 18th April, 1879, three feet outside the entrance, under the right-flanking wall, in the brown earth, with bones of hare and goat.

The other stones found in the cave, that show traces of human use, will be better described collectively, and separately alluded to in passing. They are invested with a peculiar interest by their association, in the same deposits, with other relics of man and remains of the Irish elk and bear. But five of them are recorded from the brown earth—by far the largest proportion having been found in the second or grey stratum, in which the bones of Irish elk were most numerous. With one exception, they are all worn and more or less rounded fragments of the old red sandstone rocks, similar to the stones in the drift-beds of the valley and in the surface-soil.

Sharpened Stones or Rude Celts.

No. XXVIII. A worn piece of purplish, micaceous sandstone, is of the flattened ovate shape of some Celts. This natural similarity was completed by art, for the extremity is ground down on both sides to an edge. Its sides, moreover, were chipped like the hammer-stones in the following group, among which it is also numbered. It was found in a rock-crevice with the knife-handle (No. 4, above), and bones of bear.

No. XLIV. Is a tapering piece of sandstone, ground down on both sides at the tapering end. This implement was found more than twenty feet outside the cave's mouth, in the brown earth.

Hammer-Stones.

Of the thirty-five specimens preserved, twenty-seven may be termed hammer stones. These were of shapes convenient for using in the hand, and show unmistakeable marks of having served for striking and cleaving with, possibly for smashing the bones to get at the marrow. Some had merely lost a chip or two from their edges, while others, such as Nos. VI. and VII. (Plate XIII., fig. 10), and No. XXVII.

* Mr. Kinahan considers this Celt to be the green basic felstone (the eurite of Daubuisson), so characteristic of the cambro-silurian of Waterford, Wexford, and Wicklow.

(Plate XIII., fig. 11), have both edges chipped round the same end by being repeatedly struck, first on one side and then on the other, reminding one of the "hammer-stone" of red sandstone found in Kent's Cavern, and represented by Evans, in his "Stone Implements," Fig. 402.* Nos. VI. and VII., were found at sixteen to nineteen feet from the cave's mouth, with a marine mussel shell a limpet and the human bones in the calc tufa, near which also occurred several other chipped stones. No. XXVII. was found in the upper part of the grey earth in the "chimney chamber" (section D).

These rude stone implements, used by man, but formed by nature, were frequently of unusual shapes, probably having been selected for that reason. The Celt-like form of No. XXVIII. has been mentioned above. No. X. is singularly flat and thin for a worn stone and suitable for dividing objects with; No. XXVII. is rectangular, except at the chipped end; No. XXXIV. would strike the most unobservant by its resemblance to a pear. The projection, where the stem ought to be, is the part of this stone that is chipped, the rest of the surface (except some marks on the side) being very smooth. The broad end was, doubtless, held in the palm, and the pitted or chipped point was used for striking.

This suitability for being grasped by the side (usually the thickest) which is opposite the chipped part, may be observed in almost every case of these hammer stones.

Two, however, Nos. XXXVIII. and XXXIX., seem to be specially adapted for attaching to a thong or gad round one end, and for striking with the other end, which is chipped in both cases. In the latter (a worn piece of limestone) the groove for such an attachment is natural, but in the former (a sandstone) it consists of chips taken off the opposite edges. No. LII. is most peculiar, reminding one of the head of a pick, though rounded.

Besides these chipped hammer stones, of which four may be counted from the brown earth and twenty-one from the grey stratum, there is another class.

Rubbing or Grinding Stones,

whose surfaces are ground flat, but whether done by man or not it is not easy to say. Two of these are from the grey earth, and one from the pale, sandy earth below it.

Pot Boiler.

One flattish, rounded lump of sandstone has a worn, discoloured surface, as if it had been in the fire. It may have served as a pot boiler, or stone heated in the fire for boiling purposes, as a deep notch on one side would hold a gad passed round it. It was found with the human bones and charcoal, fourteen to seventeen feet from the entrance, in the grey stratum.

* In speaking of similar hammer-stones, the above author remarks—"They may have been used for breaking up the bones for the marrow, which seems, from the fractured condition of all the bones containing it, to have been a favourite food among the French cave-dwellers."

Burned Stones.

Two other pieces of sandstone, Nos. XI. and LIV., are cracked and burned to the centre, as if they had been long exposed to fire, No. LIV. especially so. The latter was found with the human bones in the grey stratum just mentioned.

Perforated Stone.

No. XXIX. is a flattish, worn lump of sandstone, found with bones of the Irish elk and bear in a seam of dark earth, under the overhanging wall to the right, below the general level of the grey earth. It has remarkable holes or pits on both sides of it, which appear to be too regular to have been entirely the work of nature. Its edges, too, are chipped by blows.

Pounder.

No. L., a round lump of hard sandstone conglomerate, presents a surface like the end of a large pestle which is remarkably battered. The shape and weight of this stone is suitable for pounding with.

While the most undoubted evidence of man is afforded by the celts, and by many of the hammer-stones, others of the latter, and of the other classes of stones above mentioned, would not have attracted attention if found alone. Taken together, however, they form an interesting series, illustrative of the habits of the cave men, whose remains and other relics were found with them.

It would seem strange that so friable a substance as sandstone should have been chosen, were it not that flint is rarely found in the district, and that sandstone pebbles of convenient shapes are so abundant. Accordingly, no flint object of human workmanship was found in this cave.

VI.—Summary and General Conclusions by G. H. Kinahan, M.R.I.A. A. Leith Adams, LL.D., F.R.S. and R. J. Ussher.

The history of the Ballynamintra cave, as elicited by a study of its configuration, deposits, and animal relics, appears to be divisible into the following periods :—

1. Formation of the rock cavity through aqueous agency, and deposition of the gravel.
2. Deposition of the stalagmite on the gravel-floor, and inhabitation of the cave by bears.
3. Partial breaking up of the stalagmite floor, and intrusion of the pale sandy earth, enveloping the broken stalagmite.
4. Accumulation of earth accompanied by the deposition of the calc tufa. Inhabitation of the cavern by men who were contemporaneous with the Irish elk, and occasionally by bears.

5. Cessation of calcareous deposits. Continued accumulation of earth, and occupation by man, now using carved bone implements and polished celts. Gradual disappearance of the Irish elk, and establishment of domesticated races of animals.

6. Abandonment by man of the cave, which becomes the resort of foxes and rabbits, as at the present time.

The pauses and interruptions in the filling-up of the cave are marked by the seams of stalagmite in the gravel, the floor of crystalline stalagmite, the charcoal seam and the calcareous seams in the grey earth, and the layers of small stones in the brown earth. These may all have formed successive floors terminating with the surface horizon of the brown earth.

First Period.—Formation of the cavity and deposition of the gravel.

In the second part of this report it has been suggested that the formation of the Ballynamintra cave has been due partly to subterraneous drainage, and partly perhaps to the wind waves of a sea or estuary. The district must at the time of the cave's formation have been in a very different condition from its present one. Had a subterraneous stream flowed through the cave the land must have been at a higher level than the cave, and the tract of low flat ground now in front of it, and 12 feet or more below the floor of the cave, must have since been reduced to its present level. For waves in connexion with the sea to have gained access to the cavity the whole country must have stood at about 70 feet lower than now. In favour of wave-action is the worn appearance of the rocks along the scarp, which in some places are undercut, and in others are scooped out into recesses and cavities, the most remarkable of which is the cave we are treating of. Its roof and sides, so strikingly arched and smoothed, for more than 20 feet from its mouth, and its roof dipping from the entrance inwards, are suggestive that waves charged with detritus may have hollowed it out.

On the other hand, this may have been due to a tranquil stream flowing through it for a lengthened period, and the fine gravel so uniform in size, and more or less rounded, was doubtless deposited by a stream.

Indeed if this were so we must abandon the idea of sea-waves having had anything to do with the cave, for the excavation of the valley in front of it in the formation of an estuary would have left the cave as now in an elevated cliff escarpment. This would have precluded its ever after serving as a subterraneous channel for the drainage of the district.

The remarkable hollowing of its left side, ending below at a certain level, shows that the stream may have continued to wear away that side long after the bottom had been filled with gravel.

That the gravel stratum in the cave was once at a higher level is shown by the gravel bench along the left wall in cross section A. That it was deposited in water is strongly corroborated by the absence of animal remains in it.

Second Period.—The Cave ceases to be a River-channel; is inhabited by Bears, and the Stalagmite Floor is formed on the gravel.

The stream that flowed through the cave does not seem to have ceased all at once, giving place to the stalagmite deposit; for not only was the gravel cemented by the calcareous material in places into a hard concrete mass for several inches in depth, but it contained thin seams of pure stalagmite, overlaid again by gravel, showing that the calcareous matter was coming in both during interruptions in the deposition of the gravel, and also while it was being deposited.

At length no more gravel was deposited, and the cave ceased to be the channel of a stream, the ground in front having probably been excavated by a broad river that ran down the Brickey valley, so as to leave the cave high and dry.

Upon this change taking place, the cave seems to have become the habitation of bears, which died there, as the bones of one of these animals in their natural connexion were found embedded in the lower part of the stalagmite masses that had been formed on the gravel.

The digiti and teeth of deer, also found in the stalagmite, may have been carried in by the bears.

When the gravel had ceased to be deposited, the stalagmite floor formed, layer upon layer, until it attained in places a thickness of 3 feet 6 inches, or more. From the way in which it rose, until it culminated under the great chimney on the right, shown in cross section F, it is probable that this upward opening, through which so much other material was subsequently intruded, was a chief source of the stalagmite. Stalactites also were doubtless formed on the roof, though of these no vestiges were found but a broken pendant embedded in subsequent deposits.

The high level of the stalagmite floor, a little beyond the 24th foot, where there was only an interval of 6 inches between it and the roof, formed a barrier to the entrance of any animal larger than a fox into the inner cavity, and, accordingly, no ancient animal remains were found in the latter situation.

Third Period.—Break-up of portion of the Stalagmite Floor and deposition of the Pale Sandy Earth.

From whatever causes ancient stalagmite floors crystallize and break up, these phenomena are common in caves, and may be observed in three others close to the cave we are treating of. In Kent's cavern much of the lower or crystalline

stalagmite was found in fragments.* The process of crystallization may be accompanied by shrinkage, which causes the mass to crack. Another cause may be found in the subsequent removal of the bed on which the stalagmite originally rested. Water trickling down through the cracked floor, and washing away the mechanical deposit from beneath it, might, in time, have effected its total break up. We find that the gravel had actually disappeared or been mixed with other deposits along the right side, as shown in sections A and B. This may be connected with the formation of the adjoining swallow holes, which doubtless owed their origin to water from above, which sought a more downward direction to escape than its former course through the cave, when the general level of the lands in front became reduced. That these swallow holes received the drainage of the cave in times subsequent to the formation of the gravel stratum is shown by their containing lumps of stalagmite and gravel, and by the fact that the course of the calc tufa was traced down to them along a descending line of fissures. Nor do we only find the gravel bed reduced where these orifices occur, but also the whole stalagmitic floor in the outer part of the cave broken in pieces, except the undisturbed bench of it that lay along the side furthest from the swallow holes. This bears out the idea that the break up of the stalagmite was completed by the gravel supporting it having been abstracted through these holes.

It is not easy tc assign an origin for the pale sandy earth in which the broken stalagmite lay embedded. Though containing some amount of calcareous matter, it was not composed of disintegrated stalagmite, but rather of the detritus of old red sandstone. How far the intrusion of rain-water from the roof-openings, percolating under the stalagmite floor, removing its old support, and bringing in fresh detritus, was equal to produce the phenomena just described, must be admitted as questionable, or how far the breaking up of a stalagmite deposit may have been owing to shrinkage is also doubtful. It may, however, be concluded that if water brought about the degradation of this stalagmite floor, its action was not extremely violent, as testified by the total absence of rolling either on the blocks or on the animal remains. Some of the latter, moreover, showed that they belonged to the bear's skeleton found in the stalagmite, as stated on page 202.

This assemblage of bears' bones, from the great depth at which they were found, and from being embedded in well-washed gravelly sand, near the swallow-holes, sustain the inference that they were washed out of their original position on the breaking up of the stalagmite floor. Accordingly these bears' bones may fairly be presumed to be of the age of the stalagmite, while others found in the same deposit with them may have been more recent.

The presence in the pale sandy earth of charcoal, and of the various other animal remains, including bones of pig and ox (the latter having a recent appearance), is difficult to be accounted for, unless we suppose that the cave was tenanted towards

* See Fourth Report on Kent's Cavern, pp. 51, 52, British Association, 1868.

the close of this period by man, the relics of whose fires and feasts were from time to time washed down through the breaks in the stalagmite floor by water that deposited the pale sandy earth. Though charcoal would, no doubt, float in sufficient water, yet a slight trickle might carry it down fissures to the very surface of the gravel, in which position it was found more than once, but no instance is recorded of its having been found embedded in the stalagmite of this cave.

Fourth Period.—Accummulation of earth accompanied by the deposition of calc tufa. Inhabitation of the cavern by men who were contemporaneous with the Irish elk, and occasionally by bears.

During this and the following period stones and earthy materials, similar to the alluvial deposits of the valley, were intruded into the cave by a slow process through the entrance and the roof-openings within, the latter being probably their chief channels of admission. Water entering the cave through these openings would have aided to extend the earthy accumulations outwards over the stalagmite barrier, overspreading the outer part of the cave in successive layers. That the deposition of these earthy strata was gradual and successive is clearly shown by the layers of calc tufa formed, one above another, during this period in the grey earth, and by the subsequent cessation of the calcareous matter in the brown earth that overlaid it. This is corroborated by the sequence of animal remains in the grey earth and in the brown earth, as well as by their dissimilar colouring, the Irish elk being characteristic of the former stratum, while domestic animals were most plentiful in the latter. These are points of special importance, as they show that the human remains, implements, and charcoal-bed found with remains of the Irish elk in the grey earth, were deposited there contemporaneously with them, before the domestic races of the brown earth had become common. How different would it have been had all been hurled together pell-mell into the rock cavity! Such a theory is further excluded by the absence of water-action or rolling on the animal relics. Again, as shown in the third part, the intrusion of the human and animal relics through the roof-openings of the inner cavity is negatived by the fact that no ancient exuviæ nor implements were found beyond twenty-three feet from the present entrance, although we have seen that the inner cavity, which was beyond these limits, seems to have been the great reservoir of earthy materials derived from its chimney-holes, from which they drifted into the outer part of the cave. Had the older animal remains been drifted along with these from the inner cavity, we could not have failed to find them there; while, on the contrary, the large amount of material we removed from that part of the cave yielded nothing but recent bones of rabbits and foxes, while in the outer part of the cave remains of man, Irish elk, bear, &c., were abundant.

The intimate association of human remains and implements with the bones of the latter animals in the two uppermost deposits shows contemporaniety.

The charcoal and calcareous seams, moreover, mark successive floors or stages during the slow accumulation of the refuse-heap, during which man appears to have been the chief occupant of the cave, just as the bear had been when the stalagmite floor was being formed.

The condition of the larger bones, especially of those of the Irish elk, indicates the human occupation of the cavity at a time when those animals lived, during the deposition of the grey earth; and the chipped hammer-stones found in the same stratum were in all probability the very tools whereby the long bones of the ungulates were smashed in the longitudinal direction, and their articular extremities knocked off to get at the marrow. Bones of ox similarly broken are plentiful in Irish crannogs.

The indentations on a few of the pieces of bone and antler may have been made by the teeth of large carnivorous quadrupeds. The occasional visits of such animals, bears for instance, during the absence of the human occupants, in the expectation of feeding on their refuse, are indeed probable occurences, and even the human remains may have been mutilated by those animals, who left their own bones in the grey earth; but it cannot be supposed that they would have dragged in the gigantic antlers of the Irish elk, many bits of which were found in the cave, and whose presence in so narrow a cavity, can hardly be attributed to any other agency than that of man.

A noticeable feature in the bones from the grey earth, namely, their blackened surfaces and dendritic markings (as well along the faces of their fractures as elsewhere) may prove them of greater antiquity than the yellow bones in the brown earth above. This peculiar colouring was exhibited by all the human bones referable to the period we are treating of, except by those found in the cake of calc tufa, which encrusted and preserved them of a pale straw colour.

It has been suggested that the Irish elk's bones may have been brought from other places into the cave in a fossil state after the animal had become extinct, but it has not been shown that the cave-men could have had any sufficient reason for bringing in and breaking up so large a number of bones and antlers, nor why so many of the phalanges and small bones of the carpus and tarsus were carried into the cave, which is easily to be accounted for if we suppose that the limbs were brought there in the flesh.

Fifth Period.—Cessation of calcareous deposits. Continued accumulation of earth, and occupation by man, now using carved bone implements and polished celts. Gradual disappearance of the Irish elk, and establishment of domesticated races of animals.

There is nothing to show that between the deposition of the grey earth impregnated with calcareous matter, and the subsequent influx of brown earth, there was any special pause either in the accumulation of the materials or in the occupation of the cave by man. The Irish elk may have lasted into this period, though the

colour and markings on all its bones bespeak an earlier time. The cessation of calcareous matter, however, shows that the old lines of drainage had ceased to yield their carbonate of lime. This change was accompanied by a marked alteration in the colour and species of the animal remains as well as in the character of the implements. Yellow bones of existing species supplant the blackened remains of Irish elk and bear marked with dendritis. We now find for the first time remains of horse and dog, while bones and teeth of ox and goat (very scarce in the grey earth) are now abundant; pig occurs as frequently as before; hare becomes scarcer; and red deer much less common; while in the remains of fox and rabbit there is a great increase. Articles of human use belonging to this division of our record show that man had made considerable advance in fashioning his implements. Hammer-stones chipped at the edges become scarce. The polished celt, the arrow-like bone, and the other objects, show care and precision in their formation, while the amber bead found near the celt may, as we are told by a distinguished authority, Dr. Evans, have belonged to any period from the bronze age downwards. The knife-handle, he adds, is probably of what in England would be the Saxon period. The latter object, as well as the beautifully-pointed bone chisel, had unfortunately got into rock crevices, but (unless some traces of calc tufa on the chisel mark it as of greater antiquity) we might judge from their colour and workmanship that both these articles belonged to the time of the brown earth.

Sixth Period.—The cave abandoned by man becomes the resort of rabbits and foxes.

The accumulation of the brown earth continued until little of the cavity was visible. Man no longer resorting to such a refuge, or not finding any longer sufficient room there, abandoned it; whereupon it was taken possession of by the fox and the rabbit. Their recent remains and burrows found in the earthy accumulations of the inner cavity show that it was their special retreat.

Conclusion.

The Shandon and Ballynamintra caverns, occurring in the same valley and within a few miles of each other, have established important facts in relation to the post-pliocene history of Ireland. The former disclosed evidence of the presence in the southern portion of this island of the mammoth, horse, reindeer, and bear, and the latter has established the contemporaniety of man with the Irish elk and bear. It is seldom that such limited cave-explorations have been more amply rewarded. The Shandon cave, discovered by mere accident, has been the means of instigating a desire for further researches in the rock cavities on the "scars" along the Dungarvan valley. The first explored is the subject of the foregoing pages, and others equally if not more productive may await the labours of the cave-hunter.

Notes added in the Press.

Referring to Caves mentioned page 180.

1. Cave No. 13. Search having been made, June, 1880, among the rubbish where this cave is stated to have been, a molar tooth of the *Cervus megaceros* was found, whose condition betokened that it had lain in cavern deposits.

2. Cave No. 14 has been explored, and yielded such evidences of human occupation as jet, objects of carved bone and iron, slag, whetstones, flint chips, marine shells, broken bones of domestic animals, charcoal and burned stones.

Referring to page 181.

3. In Cave No. 16 portions of a stratum of coarse gravel have been found, adhering to the base of the stalagmite, and analagous to the gravel (5th stratum) in the Ballynamintra Cave.

Referring to page 181.

4. Cave No. 26 has been found to contain a kitchen midden, probably in connexion with the Dun or fort above it. This contained a quantity of coarse, broken, handmade pottery, full of quartz grains and charred; a rude stone hatchet formed, not like a celt, but by chipping a suitably shaped stone to an edge, with grooves for attachment to a handle; shells of river mussels; broken bones of domestic animals; charcoal and burned stones or pot boilers.

VII.—Explanation of Plates.

Plates IX., X., XI., XII., XIII. and XIV.

Plate IX.

View of the country around the Ballynamintra Cave, flat ground margined with scarps, Knockmeel-down in the background. By W. E. L'Estrange Duffin.

View of Ballynamintra Cave from near the Cappagh Railway Station. By G. H. Kinahan.

Map and sections of the ground at the Ballynamintra Cave. By W. E. L'Estrange Duffin.

Plate X.

Map of the low ground between the Blackwater and Dungarvan Bay, showing the margins of the ancient estuaries. By G. H. Kinahan.

Plates XI. and XII.

Plan and sections of the Ballynamintra Cave. (The level of the datum line on which the sections are made is 76·07 feet above the Ordnance zero level, or 68 feet above the mean level of the sea.) By G. H. Kinahan and R. J. Ussher.

Plate XIII.

Fig. 1 and fig. 1a.—Opposite faces of bone kife-handle. From a crevice. List of implements, No. 4.

Fig. 2.—Pointed bone instrument, point worn. From the grey earth. List of implements, No. 3.

Fig. 3.—Shaft of a broken bone implement, arrow or harpoon (?), showing rémaining barb or prong, with traces of another broken off. From the brown earth. List of implements, No. 5.

Fig. 4.—Bone chisel, formed from the metatarsus of an ox. From a crevice. List of implements, No. 6.

Fig. 5.—Polished triangular greenstone celt. From the brown earth. List of implements, No. 9

Fig. 6.—Portion of pointed bone instrument. From the brown earth or the grey earth. List of implements, No. 7.

Fig. 7 and fig. 7a.—Outer face and edge of a fragment of the brim of a hand-made earthen vessel. List of implements, No. 2.

Fig. 8 and fig. 8a.—Marginal and side views of an amber bead. From the brown earth. List of implements, No. 1.

Fig. 9.—Carved and perforated bone clasp for clothing? From the brown earth. List of implements, No. 8.

Fig. 10.—Hammer stone. Flattish pebble of old red sandstone, chipped along the narrower extremity. From the grey earth. List of implements, No. VII.

Fig. 11.—Hammer stone. Flat piece of old red sandstone, chipped round one end. From the grey earth. List of implements, No. XXVII.

PLATE XIV.

Fig. 1.—Profile, fig. 1A. crown view, of the molar series, right side, lower jaw of the grisly bear, *Ursus ferox* (race, *spelæus*). From the crystalline stalagmite.

Fig. 2.—Astragaloid surface of the right navicular of the grisly bear, *Ursus ferox* (race, *spelæus*). From the crystalline stalagmite.

Fig. 3.—Tibial and navicular aspects of right astragalus of the grisly bear, *Ursus ferox* (race, *spelæus*). From the crystalline stalagmite, probably belonging to fig. 2.

Fig. 4.—Ungual phalanx of the grisly bear, *Ursus ferox* (race, *spelæus*).

Fig. 5.—Left pisiform of the grisly bear, *Ursus ferox* (race, *spelæus*). From the pale sandy earth.

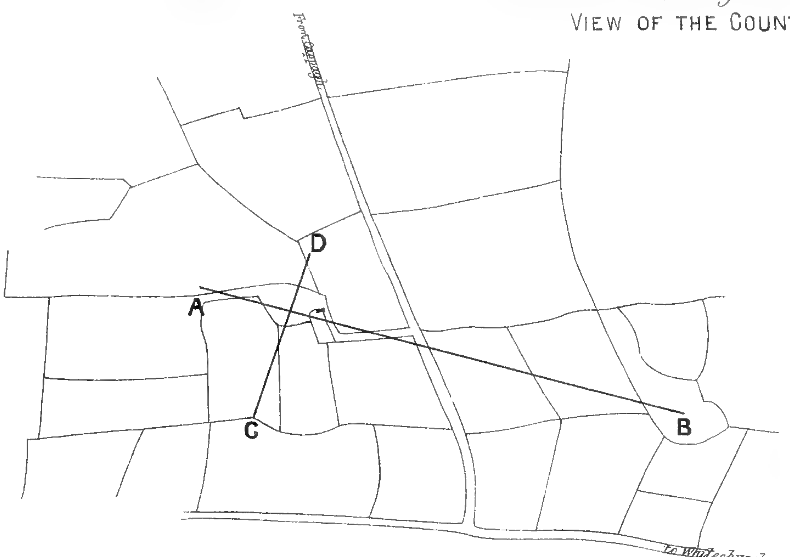
Fig. 6.—Os penis of the grisly bear, *Ursus ferox* (race, *spelæus*). From the grey earth.

Fig. 7.—Distal extremity of a right tibia of the Irish elk, *Cervus megaceros*. 7A fragment of the shaft. From the grey earth, showing longitudinal fractures.

Fig. 8.—Left distal articular aspect of the humerus of the Irish elk, *Cervus megaceros*. From the grey earth, showing marks of gnawing.

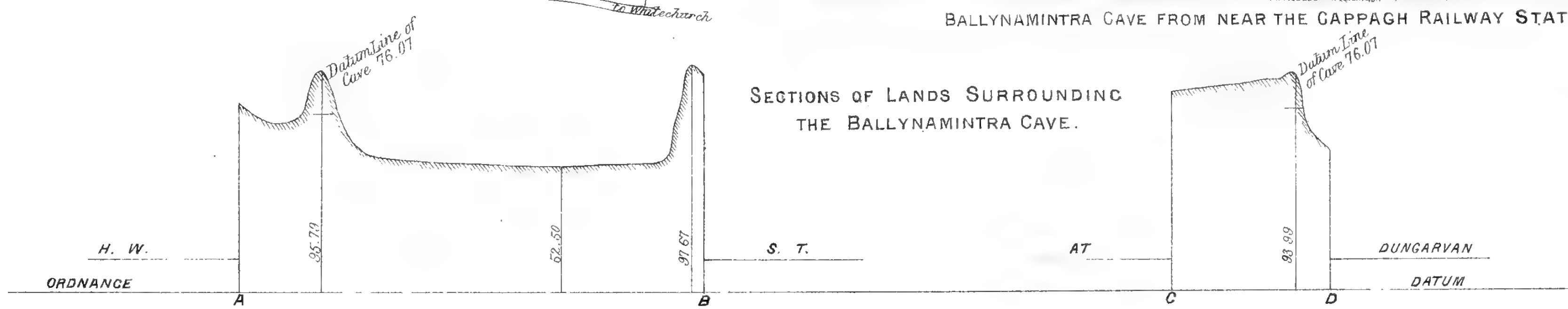
Fig. 9.—Portion of a right orbit of man. From the brown earth.

View of the Country Surrounding Ballynamintra Cave.



Ballynamintra Cave from near the Cappagh Railway Station.

Sections of Lands Surrounding
the Ballynamintra Cave.



SCALES.
Hor. 6 inches 1 Mile
Ver. 80 feet 1 Inch.

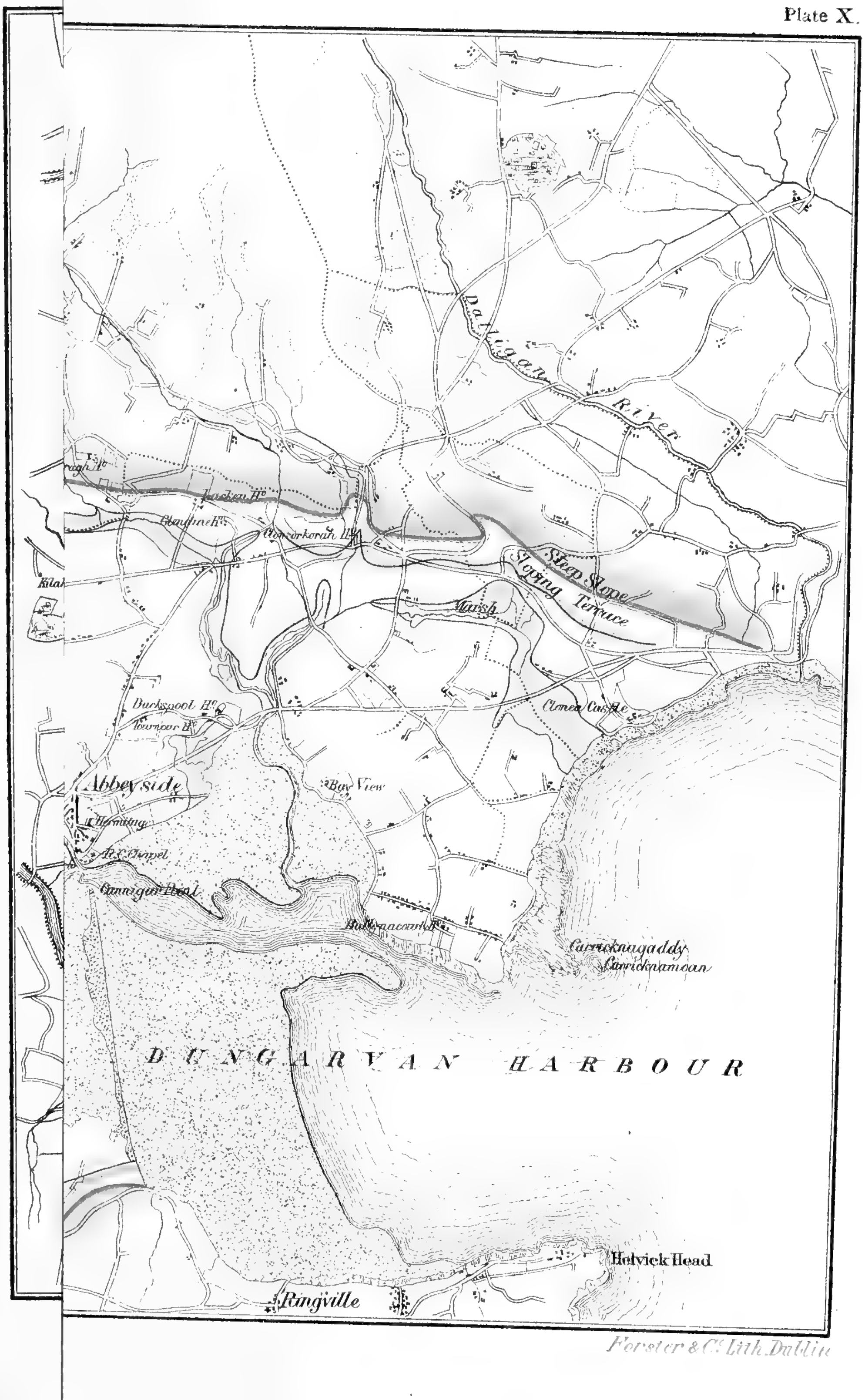
by W. E. L'Estrange Duffin.

Forster & Co. Lith. Dublin.

THE CAVES.

Trans

Plate X.



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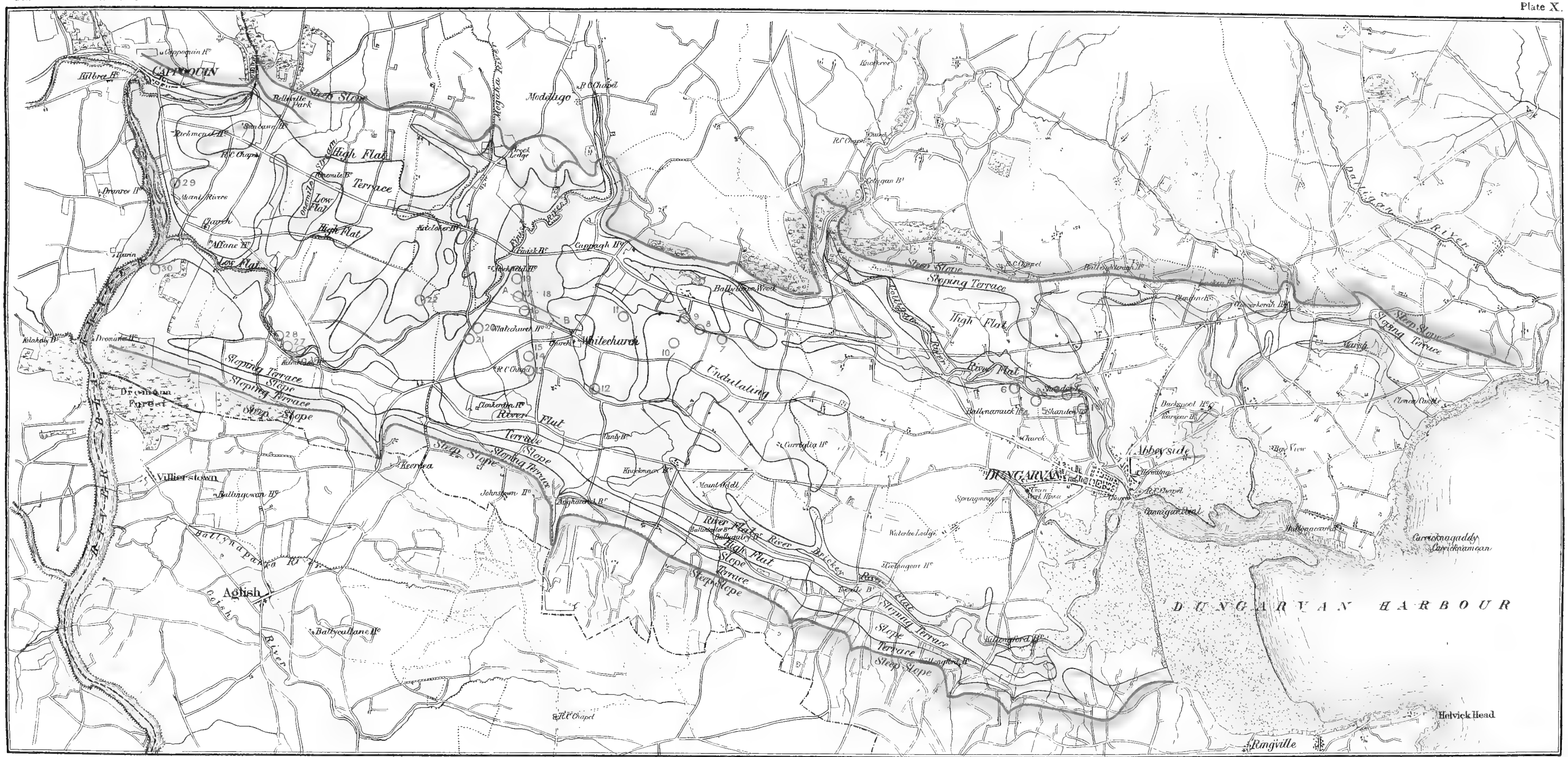
MAP OF THE COUNTRY BETWEEN THE BLACKWATER AND DUNGARVAN BAY, AND OF THE CAVES.

To accompany Report on the Ballynamintra Cave.



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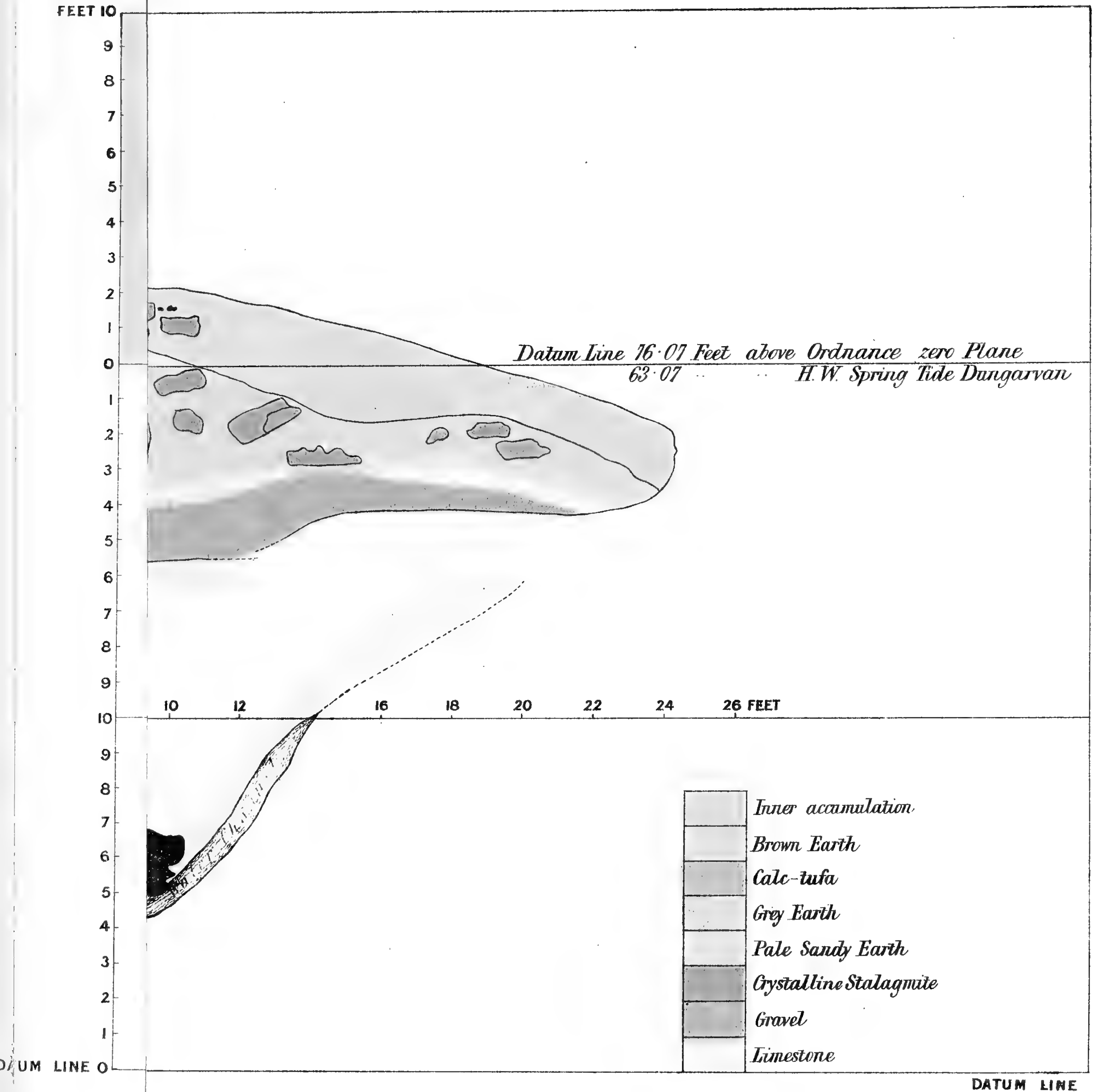
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Inner accumulation
Brown Earth
Calc-tufa
Grey Earth
Pale Sandy Earth
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PLAN AND SECTIONS ACCOMPANYING REPORT ON BALLYNAMINTRA CAVE.

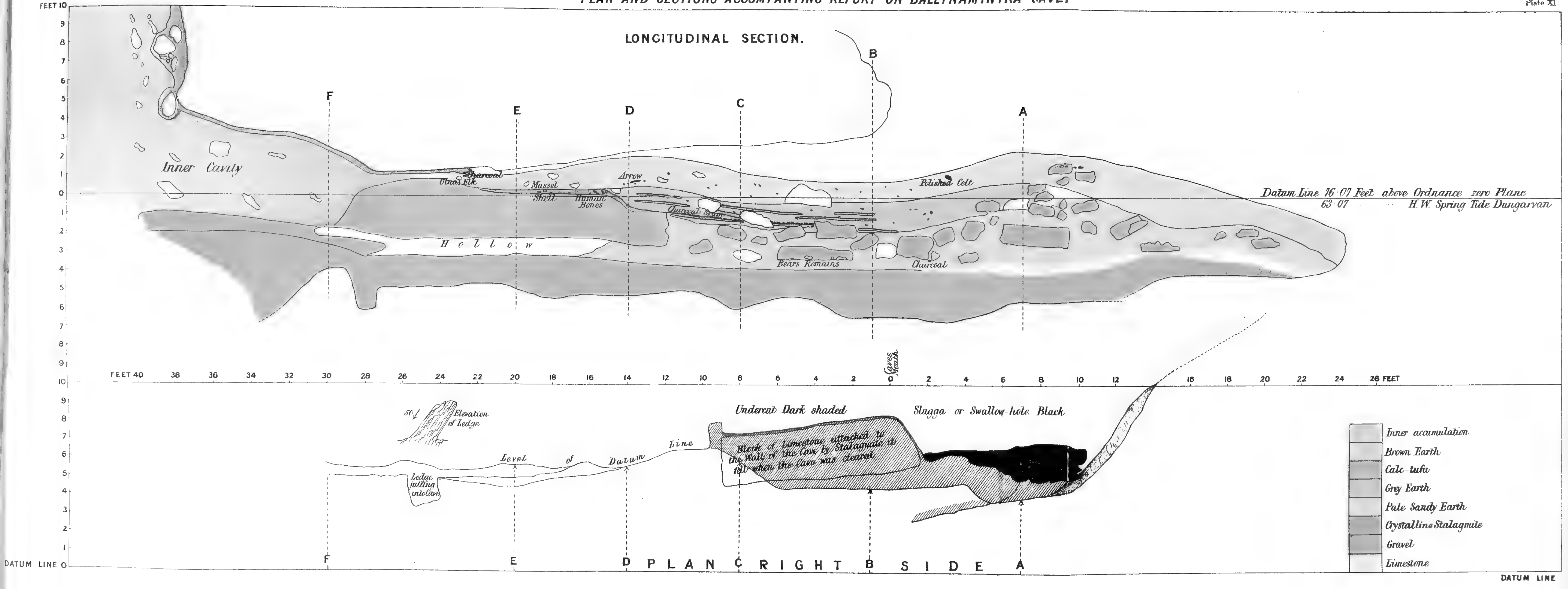
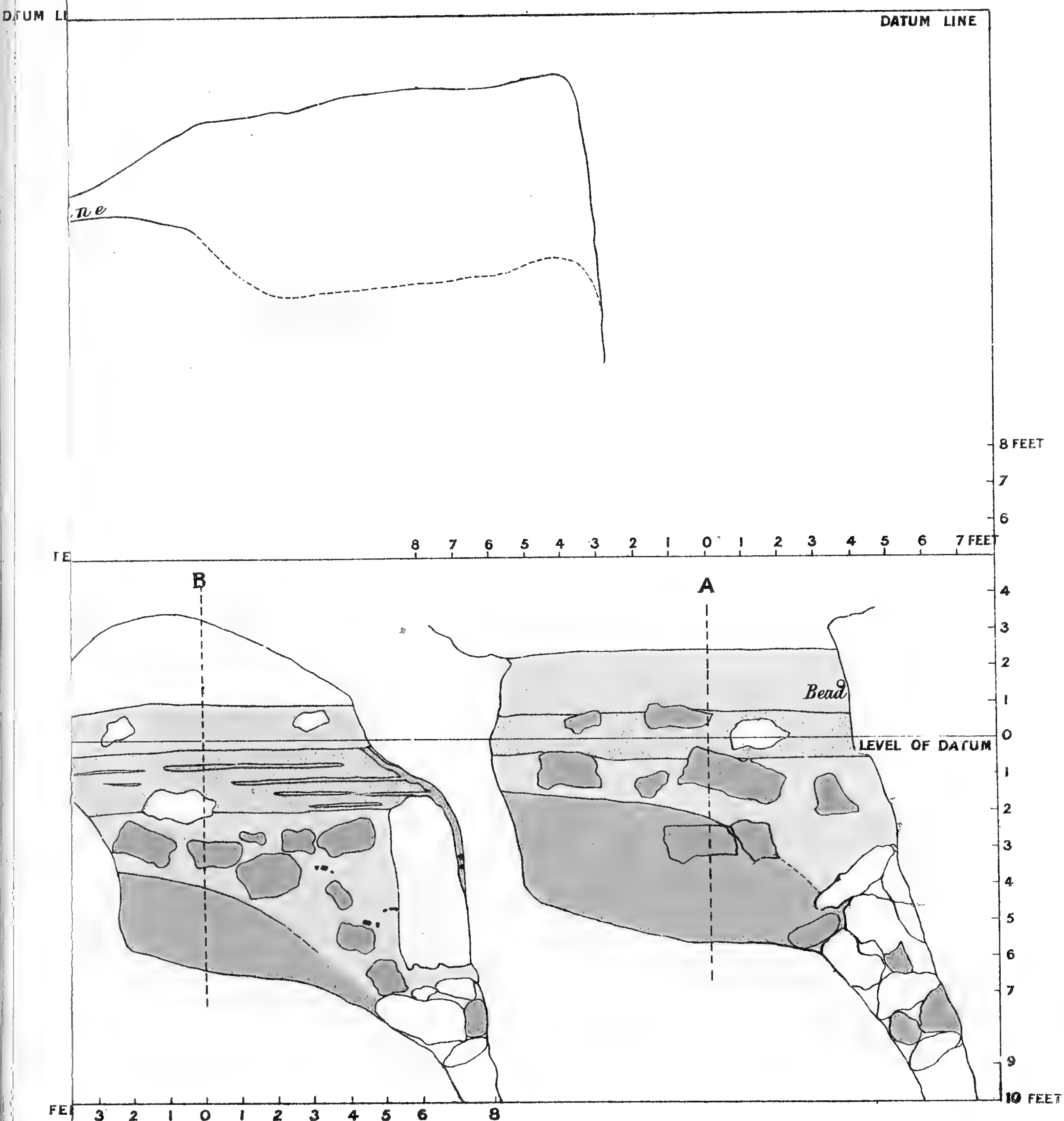


Plate XII.



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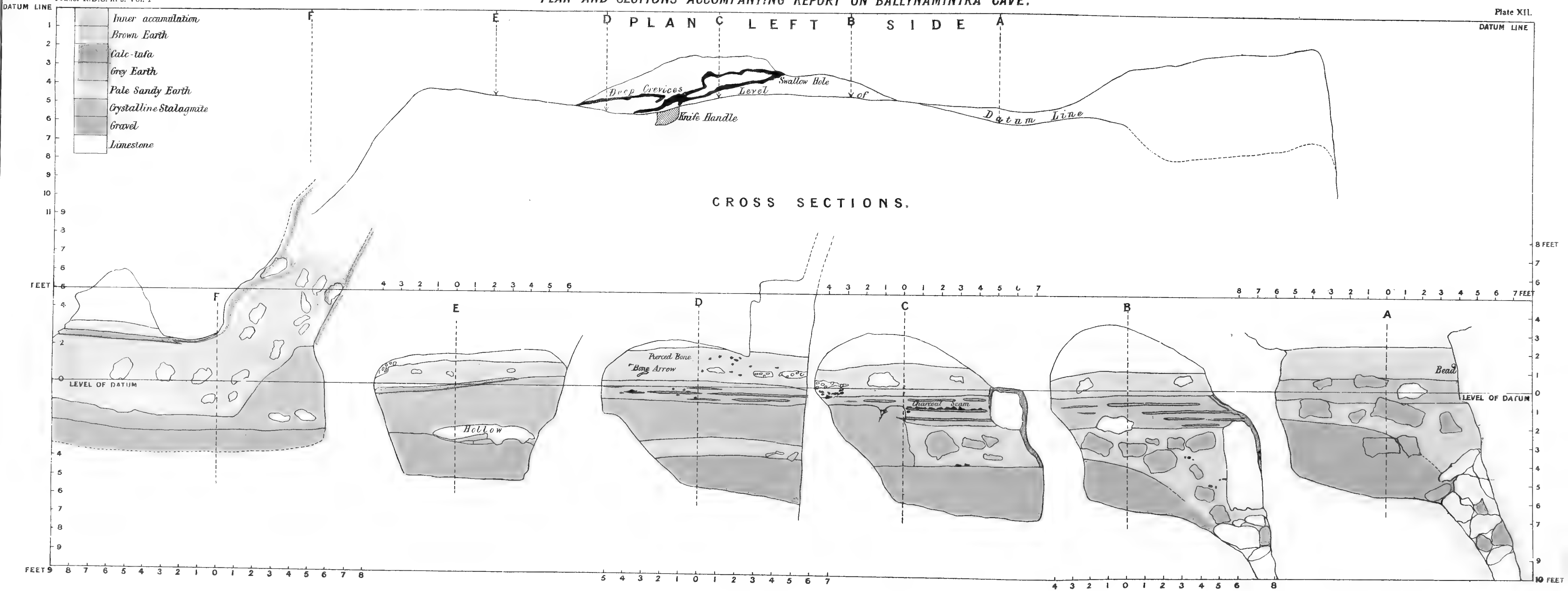
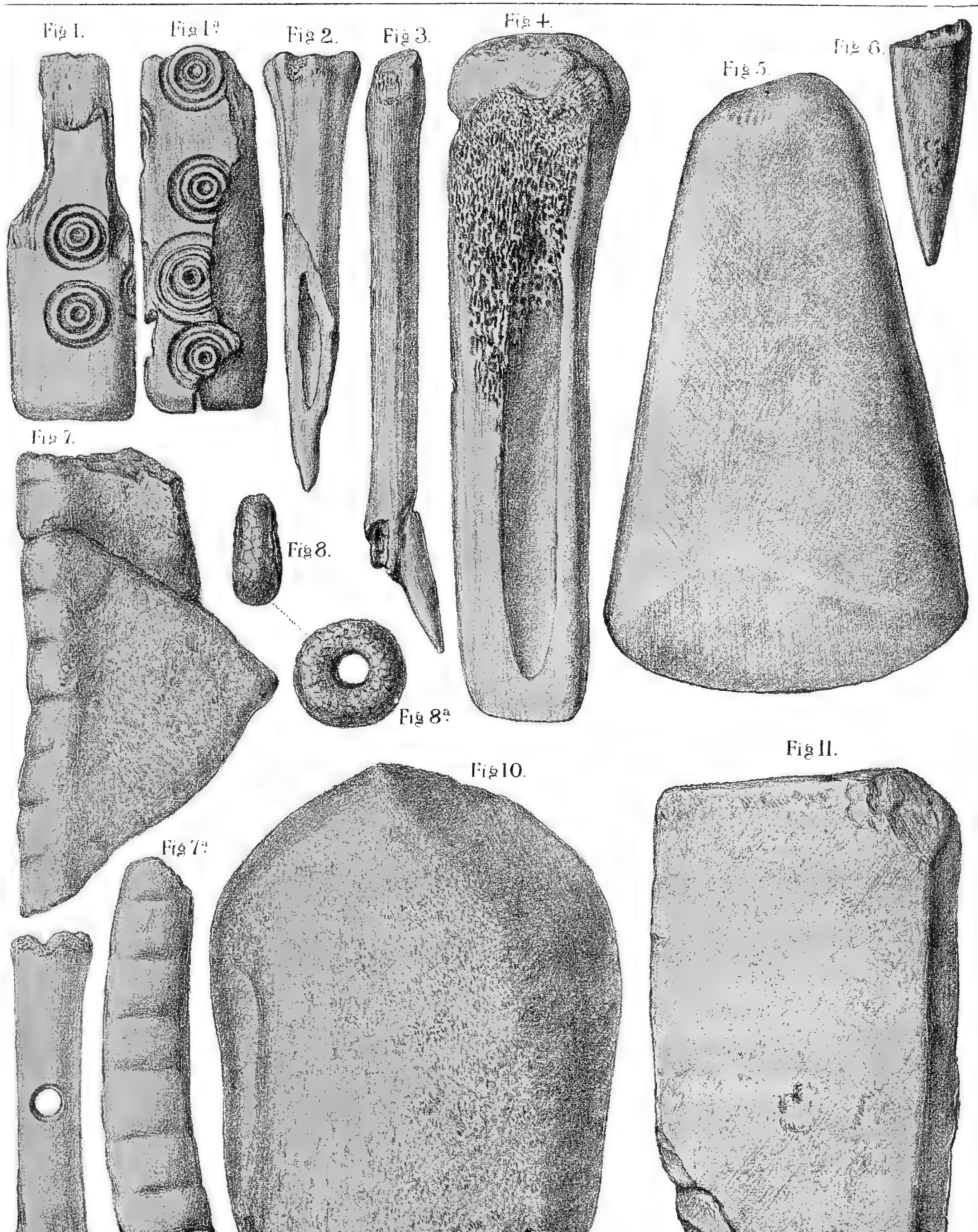
PLAN AND SECTIONS ACCOMPANYING REPORT ON BALLYNAMINTRA CAVE.

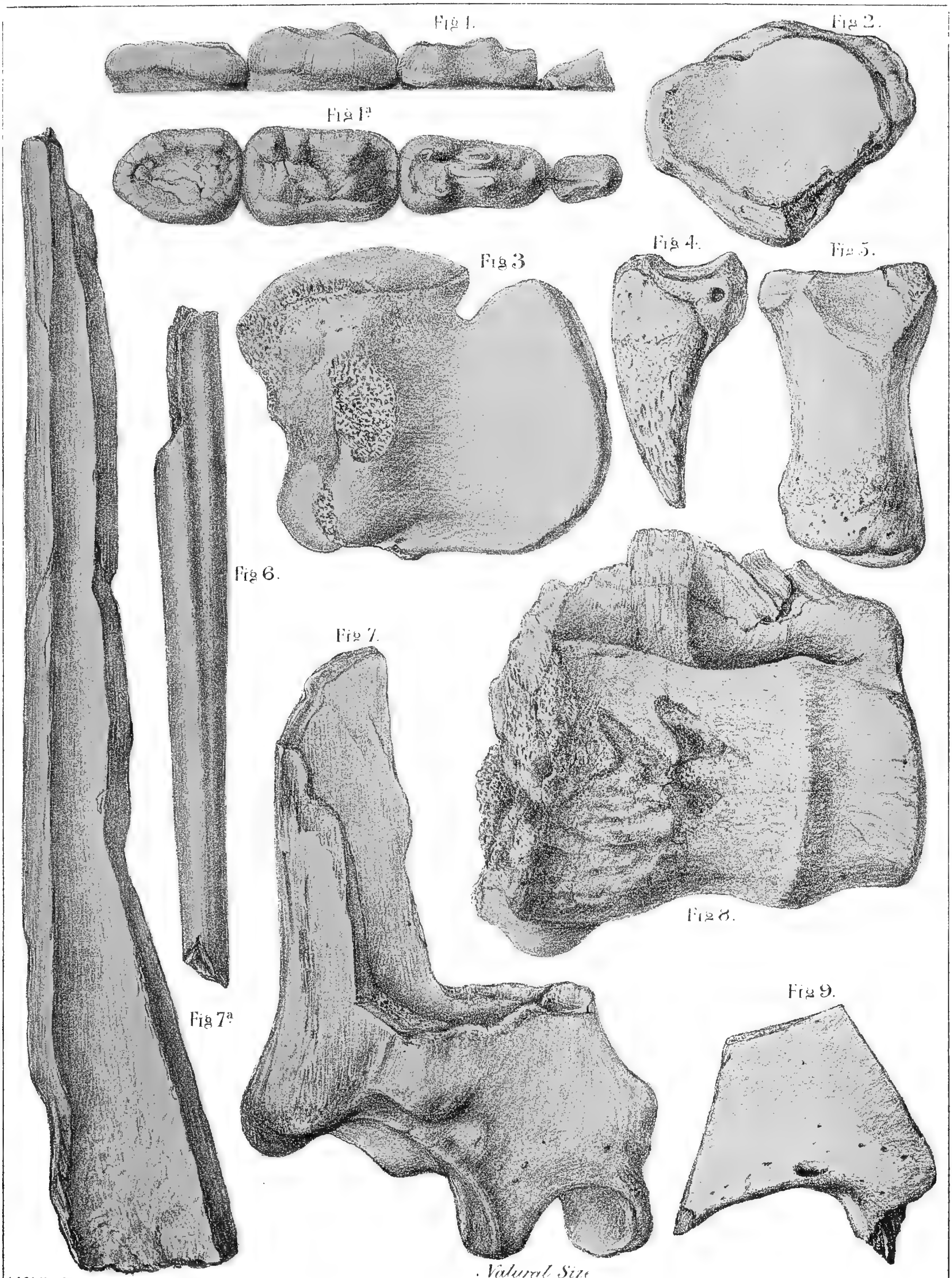




W. H. Baily del. et lith.

Natural Size

Forster & Co. Dublin.



W. H. Baily del et lith. *Natural Size* Forster & Co Dublin

TRANSACTIONS (NEW SERIES).

VOLUME I.

(Already Published.)

VOLUME II.

[January, 1882.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XV.—*Notes on the Physical Appearance of the Planet Jupiter during the Season* 1880–1. By Dr. Otto Boeddicker.—Plate XV.

DUBLIN:
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FOR HER MAJESTY'S STATIONERY OFFICE.

1882.

XV.—NOTES ON THE PHYSICAL APPEARANCE OF THE PLANET JUPITER DURING THE SEASON 1880–1. ACCOMPANIED BY SKETCHES MADE AT THE OBSERVATORY, BIRR CASTLE, BY DR. OTTO BOEDDICKER.—PLATE XV.

[Communicated by the Earl of Rosse.—Received July 6th, 1881.]

[Read November 21st, 1881.]

During the past winter pencil sketches of the planet Jupiter were made at the Observatory, Birr Castle, as often as weather permitted, and out of them a selection of twenty-five was made for publication. The drawings were executed by Dr. Otto Boeddicker, and have been reduced in the proportion of $2\frac{1}{4}$ to 1, by the Woodbury type process for the accompanying plate.

The Reflector of three feet aperture was on every occasion employed. The speculum was in fair order, having a good figure, but, having been in use for a year or more, since repolishing, it had lost some of its original brightness.

It is hoped, though less advantage can be expected from the larger aperture when used upon so bright an object as a planet than is the case with the nebulæ, that at least the drawings may prove useful in filling up gaps in series executed by other observers.

The following notes were made during the observations.

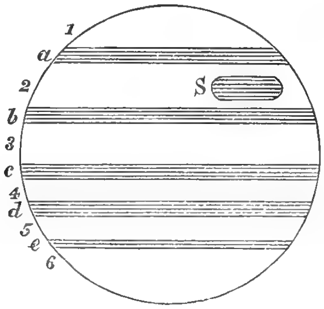
ROSSE.

Power. Usually 144, in some cases 216.

Time. The time given is the mean Greenwich time of the commencement of a drawing. The drawing was finished during 10m. on the average; the first part marked down being the most prominent feature of the planet's surface, for instance, where the red spot was at all visible, its position.

The drawings are arranged in order of longitude of the planet's central meridian, taken from *Marth's* Ephemeries in "Monthly Notices," No. 7, May, 1880.

General type of Jupiter's appearance adopted in the following remarks—



1880, November 18. Moonshine.

Drawing No. 15—Longitude 146°.57. Time 8h. 13m.

Not quite finished. Clouds prevented further drawing. Definition splendid.

b, almost bluish; *c*, reddish brown, twice as broad as *b*; on *c* a very small very bright line; *d*, nearly of the same colour as *b*; *e*, reddish; 3, white clouds. In the drawing the whole belt *b* 3 *c* a little too broad.

No. 17.—L.=171°.82. T.=8h. 54m.

Definition far from being as good as during the first sketch. Cloudy. In 3, white clouds of which that one next to the central meridian especially bright, the prec. one nearly as bright.

No. 18.—L.=186°.62. T.=9h. 19m.

b, neutral; *c*, reddish brown; 3, white clouds. The whole disc of the planet round its limb greenish.

No. 19—L.=211°.86. T.=10h. 1m.

Definition worse. No further remark.

1880, November 20. Moonshine.

No. 5.—L.=39°.00. T.=6h. 52m.

Definition bad, but later on improving. The white cloud next to the central meridian (prec.) rather bright.

No. 6.—L.=48°.56. T.=7h. 8m.

b, grey; *c*, orange. The following end of the cloud mentioned very bright.

No. 13.—L.=129°.54. T.=9h. 21m.

Definition not good, but improving; at the end of sketching very good. *b*, reddish grey; *c*, brick red. Not a very great difference between the colours of these two belts.

No. 16.—L.=160°.89. T.=10h. 13m.

No further remarks.

1880, November 26.

No. 3.—L.=7°.81. T.=10h 53m.

Sketch taken between two showers. Definition very good, yet the image of the planet sometimes very unsteady and trembling. Heavy squalls. One satellite

just emerging from the planet's disc (the satellite too small in the drawing). *S*, reddish brown, nothing particular seen on it; *a*, *b*, *d*, grey; *b* interrupted as in drawing; *c* in very strong relief, its lower edge (4) as always (also in the preceding drawings, though not specially mentioned) very bright. The sketch is not quite finished, prevented by rain.

1880, December 1.

No. 20.—L.=286°.52. T.=7h. 43m.

Definition from the middle of the sketching splendid. Southern edge of *a* very bright. *S*, red, just appearing; *b*, grey, its foll. parts next to the central meridian a little too dark; *c*, reddish brown, northern edge very bright. I thought to see two bright lines in the north prec. part of the disc.

No. 21.—L.=296°.09. T.=8h. 0m.

Definition worse, but afterwards better; *b*, uniformly dark. The foll. cloud in 3, preceding the red spot, very bright; *c*, uniformly dark.

No. 23.—L.=304°.80. T.=8h. 14m.

Not quite finished; the clock ran down; *S*, decidedly red.

No. 1.—L.=1°.38. T.=9h. 48m.

Definition bad; the small mirror was found to be covered with dew and hoar frost; *s* and *c* reddish brown; the northern edge of *c* (4) very bright. I have not much confidence in the following parts of 3.

1880, December 16.

No. 7.—L.=75°.50. T. 9h. 8m.

Definition middling. Southern edge of *a* bright; *b*, almost as dark as *c*; *c*, reddish; *d*, faint.

No. 8.—L.=84°.21. T.=9h. 23m.

Definition very good, moments of an extraordinary clearness. Southern edge of *a* bright; *b*, uniformly dark; *c*, decidedly reddish, northern edge of *c* very bright; *e* visible.

No. 10.—L.=96°.40. T. 9h. 43m.

Southern edge of *a* very bright. The following parts of *d* rather faint; *e* visible.

No. 11—L.=111°·19. T.=10h. 7m.

b, in the following part interrupted as shown in the drawing; not quite finished; clock ran down.

No. 14.—L.=132°·09. T.=10h. 42m.

Very clear. *a*, very indistinctly visible; in the place of interruption in *b* I sometimes thought I saw a very faint continuation of *c*; southern edge of *c* a very small line, northern one very bright.

1881, January 7.

No. 9.—L.=87°.79. T.=7h. 34m.

Definition not good, slight fog and moonlight; *b* and *c*, reddish grey, no special difference of colour perceptible.

1881, January 21. Clear. Milky Way rather pale

No. 2.—L.=2°.82. T.=6h. 48m.

S, decidedly brick red ; *b,* grey ; *c,* greyish red ; its northern edge very bright ; *d,* faint, indistinct. In 3, white clouds, the round one next to the central meridian very bright.

No. 4.—L.=15°.87. T.=7h. 5m.

S, decidedly brick red. I sometimes thought I saw its prec. part a little darker than the whole spot ; *b,* grey ; *c,* greyish red, northern edge of *c* very bright. In 3, white clouds, the prec. one next to the meridian brightest, the part of 2 following the red spot very bright.

1881, January 30.

No. 22.—L.=296°.16. T.=7h. 17m.

Definition not good, image rather unsteady.

S, just appearing as a very faint trace ; *c,* hardly much darker than *b,* except towards its northern edge ; 4, rather bright, especially next to *c* ; *d,* very broad, gradually darker towards its southern edge. The three belts, *b, c, d,* without special spots or marks. The features on the southern hemisphere extremely faint. The clouds in 3 not very distinct, the colours uniformly greyish yellow.

No. 24.—L.=323°.14. T.=8h. 1m.

S decidedly dark red, uniformly coloured. Colours of belts not very distinct ; *c,* slightly reddish grey, a little darker than *b* ; clouds in 3 rather indistinct. The whole disc greenish yellow.

No. 25.—L.=344°.03. T.=8h. 35m.

The prec. part of *S* seemed sometimes to be a little darker than the following one. Central cloud in 3 brightest.

1881, February 5.

No. 12.—L.=126°·00. T=7h. 31m.

Very clear, bright moonlight. Jupiter very pale ; *c,* bisected, northern part slightly reddish ; *b,* a little darker in the two parts surrounding the cloud next to the central meridian, this cloud brightest in 3 ; 2, next to the southern edge of *b* and especially 4, next to the northern one of *c,* rather bright.

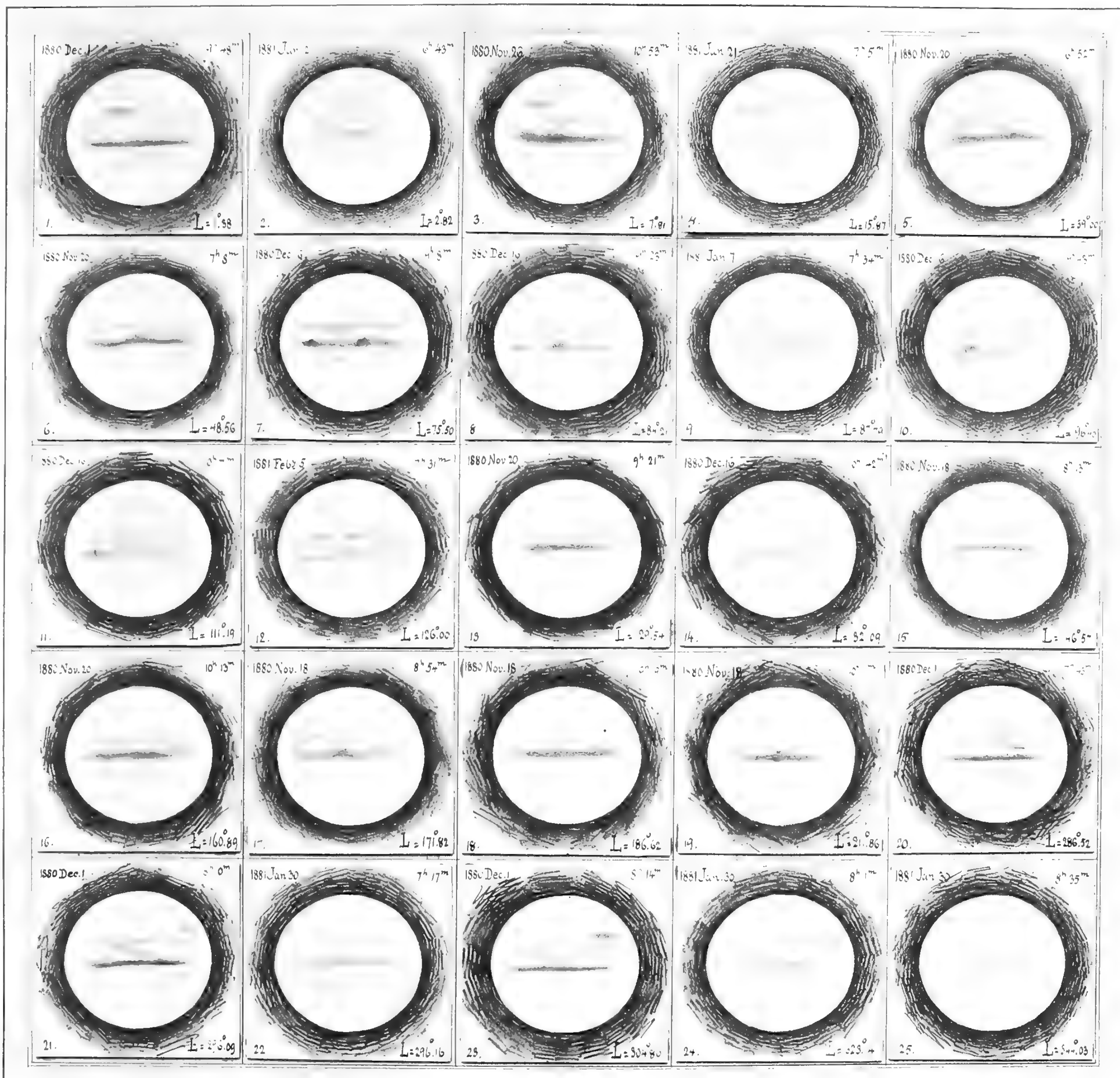
Plate XV. is, on the whole, a good reproduction of the original, but it is to be remarked throughout that the less prominent features of the planet's surface are too faint. Such is especially the case with—

a, in all the drawings. There should be none where it is totally imperceptible.

b, in Nos. 2 and 22 (where the whole of both these drawings should be darker), and in Nos. 9 and 23.

e, in Nos. 8 and 10.

In addition to this *S* should be slightly darker in Nos. 6 and 22.



Drawings of the Planet Jupiter
made with the Three-foot Reflector at Birr Castle 1880 Nov. 18 – 1881 Feby 5

OTTO BŒDDICKER DEL. WOODBURY PHOTO. CO.

TRANSACTIONS (NEW SERIES).

VOLUME I.

(Already Published.)

VOLUME II.

[February, 1882.]

THE SCIENTIFIC TRANSACTIONS OF THE ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XVI.—*Photographs of the Spark Spectra of Twenty-one Elementary Substances.* By W. A. Hartley, F.R.S.E., *Professor of Chemistry, Royal College of Science, Dublin.*—Plates XVI., XVII. and XVIII.

DUBLIN:
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1882.

XVI.—PHOTOGRAPHS OF THE SPARK SPECTRA OF TWENTY-ONE ELEMENTARY SUBSTANCES.

By W. N. Hartley, F.R.S.E., Professor of Chemistry, Royal College of Science, Dublin.—Plates XVI., XVII., and XVIII.

[Read April 11th, 1881.]

The spectra of the elements are physical constants of the greatest importance, which have hitherto been but imperfectly studied. Those spectra which have received most attention have included but little more than rays of such refrangibility as are plainly visible. The time occupied and the labour involved in making accurate observations with the ordinary forms of spectroscopic apparatus have, to a certain extent, been a bar to our knowledge of the conditions under which the elements emit characteristic spectra, and have precluded the useful applications of spectroscopy to the technical purposes of the metallurgist and chemist. Undoubtedly at the present time more reliance is to be placed on the ordinary methods of chemical analysis than on those dependent on the use of the spectroscope; there is reason to believe, however, that further research, particularly in the branch of spectrum-photography, will lead to greater refinements and precision both in qualitative and quantitative analysis than have hitherto been attained. *

The character of a photographed spectrum depends on the nature of the salt or salts in and on the surface of the sensitive film of the photographic plate, the length of period of exposure of the film to the active rays, the diactinic character of the optical train, and the rates of vibration of the emitted rays. Given an optical train as diactinic as air, and a sensitive salt capable of receiving an impression from all rays transmitted by the instrument, and we may regard a photograph of a spectrum as a permanent record of a chemical reaction distributed in time and space.

In presenting the accompanying photographs of spectra, which were obtained by means of the apparatus and processes previously described by me (Proc. R. D. Soc., Vol. 3, New Series), I am desirous of making known the excellence of this method of research and of recording for future reference, the number, the relative positions, and what I may term the graphic peculiarities of the rays emitted by various substances.

On the graphic characters of spectral lines.—The characters of the ultra-violet spectra are more strongly marked than those of the visible region, and the grouping of lines is more plainly seen by reason of the small number of air lines

* See "On the Application of the Spectroscope to the Analysis of Iron and Steel." By John Parry, F.C.S. and Alex. E. Tucker, F.C.S., "Engineering," February 14th, 1879.

and their insignificent character when of lesser wave-length than 380·0. The graphic characteristics of the lines seen in the spectra of various substances may be described thus, they consist of strong and faint lines, which again may be classified as, (1), Continuous lines; (2), Discontinuous; (3), Extended lines; (4), Blotted lines, or lines with a nimbus; (5), Nebulous lines and bands.

(1.) *Continuous lines* are those most abundant in the less refrangible portions of the spectra of iron, cobalt and nickel; they extend the whole length of the spark and are accurate representations of the slit.

(2.) *Discontinuous lines* are those whose length is not so great as the distance between the two electrodes. They may proceed either from the positive or the negative electrode, or from both, and may be called long and short lines, as in the case of certain lines of cadmium; or they may consist simply of dots, as in the case of the more refrangible rays in the spectrum of zinc.

(3.) *Extended lines* are those like the 17th line of cadmium, which being sharp lines extend above and below the edge of the spectrum, or in other words above and below the points of the electrodes. The extension of the line is caused by the glow or "glory" surrounding the electrodes being very intense. These lines are the longest and are continuous.

(4.) *Blotted lines,* or those with a nimbus, are well represented by the least refrangible ray in the photographed spectrum of magnesium, the wave-length of which lies between 448·1 and 447·9. It is visible in the violet region. The nimbus is characteristic of a great intensity of brilliancy or of chemical activity. The nimbus of a line may be much lessened in width, and in fact made to assume the character of nothing more than a slight widening of the line at each end, by greatly reducing the width of the slit of the spectroscope, as for instance, from the $\frac{1}{500}$ to the $\frac{1}{1000}$ of an inch.

(5.) *Nebulous lines* are those which are destitute of the sharp clear-cut appearance of most metallic lines. The air bands and lines at the less refrangible end of all the photographs are for the most part nebulous in character. They vary considerably in intensity. Irrespective of the air lines constantly present, nearly all varieties of lines may be noticed in one spectrum, as for instance, in that of cadmium.

It is necessary to state the conditions under which these spectra were obtained, and then to describe carefully the lines of cadmium, so that when an apparatus has been adjusted so as to yield photographs exhibiting the characters of these lines distinctly, it will be known that it is accurately focussed for all spectra taken in a similar manner.

Manipulation necessary to secure sparks of constant intensity, &c., &c.—The battery power, size of coil, and condensing surface, must all be proportional to the distance between the electrodes. When the battery power is too weak, the stream of sparks is intermittent, and with badly conducting electrodes may cease

altogether. When the condensing surface is too small the sparks are not sufficiently brilliant, a lengthened exposure is then necessary to obtain photographs, and these are frequently wanting in faint lines and minute details; moreover, an increased number of lines are discontinuous.

When the battery power and coil are of the right proportion, but the condensing surface too large, the sparks are delivered slowly, but they possess too great a brilliancy. The effect of this is to obliterate the distinction between short and long lines, lines usually discontinuous are made to extend in an unbroken line across the spectrum. The rapidity of the passage of the sparks should be at least at the rate of 500 or 600 per minute. The battery and coil previously described by me (Proc., R. D. Soc., Vol. 3, New Series), are suitable for such sparks.

The distance between the electrodes is measured by a gauge consisting of a piece of plate glass about $\frac{1}{4}$ of an inch or 5^{mm} in thickness. This is placed between the points, and they are made to touch it, when it is withdrawn without disturbing them.

The slit aperture is measured by a micrometer screw, it may vary between $\frac{1}{400}$ and $\frac{1}{600}$ of an inch in width or be diminished in special cases to $\frac{1}{1000}$ with advantage.

Particular care is necessary to keep the slit free from dust and the condensed vapour of volatile metals. The use of a condensing lens of short focus will prevent the condensation of metallic vapours on the slit. I have at various times used a condensing lens of three inches focal length, but I prefer to place the spark close to the slit, the slit itself being covered with a thin plate of quartz. This not only keeps off metallic vapours but also particles of dust. It is, of course, cleaned simply by wiping with a leather. There is really no difference in definition between photographs taken with and without a condensing lens.

When the metallic points wear away by reason of the excessive volatility of a metal, sometimes a portion of the spark does not play directly opposite the slit. In such a case the quartz plate is of the greatest utility, as by a glance one can tell from the reflexion from its surface whether or not the slit is completely covered by the spark. Good, thick, and broad electrodes are commonly productive of the most uniform results. The character of the lines varies with the conductivity and volatility of the electrodes; their intensity, as a rule, increasing with these properties. The more volatile a metal the more continuous are its lines. The spectra of magnesium, zinc and cadmium are examples of this, while that of mercury is an extreme case. The length of spectrum obtained with the lens of thirty-six inches focal length between the air line just visible, with a wave-length of 464·4, and the cadmium line 23, wave-length 231·8, is nearly 6·4 inch (160^{mm}), with the fifteen inch lens it is 3·2 inches (or 80^{mm}). If the prism be placed at the minimum angle of deviation for any line less refrangible than No. 17 Cd. the spectrum will be longer, but the definition of the more refrangible lines will be defective.

The highly refrangible nature of the extreme lines of cadmium, which throws

the position of their foci something like six inches nearer to the lens than the foci of the visible rays, naturally causes the image of the rays to be smaller, hence the spectra all decrease in width as the refrangibility of the rays increases; at the same time, although perfectly in focus, the lines tend to become nebulous in character.

Standard Spectra.—The standard for all measurements of wave-lengths are the lines ot cadmium so accurately measured by M. Mascart. They also serve as standards of intensity and of the sensitiveness in the silver bromide film. Hence at the top generally of each plate is a photograph taken of cadmium electrodes, in order to determine the position of the lines of the other substances and as a test that the plate is of a normally sensitive character, that the development is properly carried out, the battery power efficient, and the period of exposure of the plate correct.

Of the period of exposure.—With regard to the length of time that a plate may be exposed to the rays of the spectrum, this varies for the same electrodes with the prism power and focal length of the lenses, other conditions being constant. With different electrodes it varies with their conductivity and volatility.

Considerable latitude may be allowed in the exposure of even the most highly sensitive gelatine bromide films, thus four perfectly good photographs of the cadmium spectrum have been obtained on the same plate, and developed at the same time, the first had one minute and the last four minutes in the camera.

The chief lines of the metal were equally good in each, but the faint metallic lines and the air lines were strong in the last photograph.

It is possible with collodion emulsion plates, such as those of the Rev. Canon Beechey, to obtain photographs of the principal metallic lines perfectly distinct, the air lines being either invisible or so faint as to be unnoticable. A short exposure of a very sensitive emulsion and a long continued development secures this effect.

By lengthened exposure minute traces of foreign metals betray their presence in specimens which otherwise appear of perfect purity, thus I have detected indium in cadmium, cadmium, tin and lead in indium, silver in gold, and iron in aluminium, even after great care and skill had been exercised in the elimination of all foreign matter.

The following is a table of exposures which yielded the photographs which accompany this paper :—

Magnesium, . .	1 minute.	Lead, . . .	2 minutes.
Zinc, . . .	2 ,,	Tellurium, . .	4 ,,
Cadmium, . . .	2 ,,	Arsenic, . . .	3 ,,
Aluminium, . .	3 ,,	Antimony, . .	2 ,,
Indium, . . .	2 ,,	Bismuth, . . .	2 ,,
Thallium, . . .	2 ,,	Iron, . . .	2 ,,
Copper, . . .	3 ,,	Nickel, . . .	2 ,,
Silver, . . .	3 ,,	Cobalt, . . .	2 ,,
Mercury, . . .	1 ,,	Palladium, . .	3 ,,
Carbon (graphite), .	4 ,,	Gold, . . .	3 ,,
Tin, . . .	2 ,,	Aluminium, . .	2 ,,

Description of the Cadmium Spectrum.—The lines to the extreme left hand of the photograph of cadmium which appear faint, are air lines with wave-lengths 464·4 and 463·0.

Cadmium line No. 7. λ=441·4, (Mascart).—A fine distinct line in the violet, discontinuous, coincident with an air line.

a and *b*. Two continuous lines near together, very fine.

Cadmium No. 8. λ=398·56, (Mascart).—This is an air line.

Cadmium No. 9. λ=360·7, (Mascart).—This consists of a pair of exceedingly closely adjacent lines, strong, continuous, and extended.

c. A sharp, faint, fine line, discontinuous.

d. Very faint, nebulous, discontinuous.

Cadmium No. 10. λ=346·4, (Mascart).—Shows indications of being double when the photograph is examined with a microscope and an object glass magnifying about 45 diameters. The line is strong, continuous, and extended.

Cadmium No. 11. λ=340·3, (Mascart).—This is a single line, strong, continuous, and extended.

e and *f*. Between lines No. 11 and No. 12 of cadmium, there are two small discontinuous lines which are nebulous.

There are at least forty of such lines in the spectrum, some of these are sharper and more distinct than others. There is a considerable number lying between the lines Nos. 12 and 17. Omitting air lines, which are easily recognisable, we come to—

g. A sharp, distinct, continuous line. This is coincident with one of the strongest lines in the spectrum of indium, and it probably belongs to that element. It is very near No. 12.

h. This is comparatively a faint line, but very distinct and closely adjacent to the line No. 12 of cadmium.

Cadmium No. 12. λ=328·7 (Mascart).—Sharp, discontinuous if the spark be feeble or the exposure short, thin in the centre if the spark be strong and the exposure sufficient.

There are many discontinuous lines or dots between Nos. 12 and 14. Fifteen are easily counted.

Cadmium No. 14, (Mascart).—Not measured. Strong, continuous line with much of the appearance of an air line.

Cadmium No. 15, (Mascart).—Not measured. A strong fine line somewhat like an air line.

Cadmium No. 16, (Mascart).—Not measured. A very fine continuous line.

i. Next to the former a very fine discontinuous line which proceeds from one electrode only.

j. A very fine discontinuous line of the same character as *i*.

k. A fine, faint, continuous line near cadmium, No. 17.

Cadmium No. 17. $\lambda=274 \cdot 3$ (Mascart).—A strong, continuous, single, sharp line, with a nimbus and extended. This is the longest line with Nos. 18 and 24.

l, m, n. These lines, sharp, faint, and discontinuous, proceeding from one electrode only.

Cadmium No. 18. $\lambda=257 \cdot 4$, (Mascart).—Strong, sharp, single, continuous, extended and with a nimbus.

Cadmium No. 19, 20, and 21.—With four or five other fine discontinuous lines, due to the metal, occur between Nos. 18 and 22. Of these No. 19 appears to be an air line.

No. 20 is rather stronger than 19, and sharp.

No. 21 is near Nos. 22 and 23. It is not a strong line and is discontinuous.

No. 22 is distinct, rather weaker, nearly discontinuous, with slight nimbus.

Cadmium No. 23. A long line. $\lambda=231 \cdot 8$, (Mascart).—Strong with nimbus.

o. A fine but weak and discontinuous line. This is coincident with one of the strong lines of indium, and it probably belongs to that element.

p. A strong continuous line exactly similar to No. 15.

Cadmium No. 24. $\lambda=226 \cdot 5$, (Mascart).—Strong, continuous, extended, and with larger nimbus. With Nos. 17 and 18 it is one of the longest lines.

q. This is a sharp, continuous, faint line.

Cadmium No 25. $\lambda=221 \cdot 7$, (Mascart).—A faint line, scarcely continuous.

Particulars regarding the electrodes or the specimens from which they were prepared.

Specimens marked * were from the collection photographed by the late Dr. Miller, of King's College, London.

* *Magnesium.*—The metal supplied by the Magnesium Metal Company, Patricroft, near Manchester is of great purity, and was employed.

* *Zinc.*—A sample of very pure distilled zinc.

* *Cadmium.*—Several specimens of cadmium were photographed, but the one the spectrum of which is here reproduced, was the purest.

* *Aluminium.*—By greatly lengthening the exposure, the lines of iron are made to appear.

Indium.—Three specimens of this metal were examined. They were given me by my friend Mr. W. G. Lettsom. One was prepared by Dr. Böttger, another was purchased in Freiburg. Neither of these were pure. The third was prepared by Professor Richter, and is the one photographed here.

Copper.—The copper was prepared by dissolving electrotype copper, which was found to contain only a little sulphur, in nitric acid, precipitating the oxide by potash, washing the oxide very thoroughly, reducing in a current of hydrogen, and subsequent fusion of the metal.

* *Silver.*—A most carefully prepared specimen of pure silver.

Mercury.—This was a very good sample of the commercial article. It was digested for some time with strong sulphuric acid. The method of obtaining the spectrum of this element was the following :—A quill glass tube of an inch or so long was drawn out at one end to so fine an orifice that the mercury would not fall through when the tube was in a vertical position. This was treated as if it were a solid electrode, being separated at a convenient distance from a small V tube filled with mercury, which was standing in a porcelain dish. Conducting wires were dipped into the upper and lower tubes, and as soon as the current passed a drop of mercury was forced through the hollow pointed tube, accompanied by the passage of a spark.

* *Thallium.*—A specimen obtained by Dr. Miller from Mr. Crookes.

Tellurium.—A specimen purchased from Messrs. Hopkins and Williams.

Arsenic.—A finely crystallized specimen in the Museum of the Royal College of Science.

Antimony.—A fine specimen in the Museum of the Royal College of Science.

* *Bismuth.*—

Iron.—Especially pure ribbon prepared by the late Dr. Matthiessen, kindly furnished to me by Dr. Russell.

* *Nickel.*—A specimen in a sealed glass tube in the form of powder, prepared by Dr. Russell for determining the atomic weight of the element, and therefore most exceptionally pure. In order to get good electrodes the metal was fused by means of a jet of oxygen burning in an excess of hydrogen. A pair of electrodes were made out of the fused metal.

* *Cobalt.*—This also was prepared by Dr. Russell for a like purpose to the above. It was fused in the same manner.

Palladium.—A purchased specimen which for some time has been in my possession.

Gold.—An extremely pure specimen, prepared with great care by Mr. Sonstadt. It was twice precipitated from its solution by a current of sulphur dioxide, and was finally fused with potassic disulphate. This preparation was given to me by my friend Mr. Manning.

Graphite.—This was a fragment from a beautiful specimen in the Museum of the Royal College of Science.

* *Tin.*— }
* *Lead.*— } These specimens were especially prepared for spectrum work.

I may here remark that the photographs which illustrate this paper are furnished from negatives which were produced from the originals on glass. They have thus, in transference from one vehicle to another, lost some of their delicacy of detail. The originals on glass cannot be properly seen unless magnified forty-five or fifty six diameters.

Description of Plates xvi., xvii., and xviii.

The plates, which are as nearly as possible facsimile reproductions of the original photographs on glass, have been executed by the Woodbury Type Printing Company.

Bands and lines common to all spectra are due to air. Sixty-six have been counted. They are chiefly seen at the least refrangible end of the spectrum in the blue and violet region.

Plate xvi.

(1.) *Spectrum of Magnesium.* The least refrangible ray which is visible in the violet consists of two nebulous but intense dots. In Watts' "Index of Spectra" the wave-length is given as 448·1 (Thalen) and between 448·1 and 447·9 (Kirchoff). Next occurs a triplet, which has the appearance of one nebulous line unless minutely examined. M. Cornu designates the four triplets in the magnesium spectrum, b in the green, b′ between lines K and L, b″ between P and Q, and b‴ between S and T of the ultra-violet solar spectrum. This is b′ with wave-lengths 383·74, 383·13, and 382·8. The next group of strong lines consists of a pair, with wave-lengths 293·49 and 292·67, a single line 285·3, and a group of four lines 280·13, 279·71, 279·45, and 278·99. For M. Cornu's measurements see Annales de l'Ecole Normale, Vol. 9, 1880; also "Determinations des longueurs d'onde," &c.; Archives des Sciences Physiques et Naturelles de Genève (3), II., pp. 119-126. Lastly, a group of five fine lines, continuous, equidistant, and very distinctly seen in the glass originals; three of them appear in the prints, namely —1st, 278·22; 3rd, 277·95; 5th, 277·69—Liveing and Dewar, "Investigations on the Spectrum of Magnesium."—Proc., Roy. Soc., No. 213, 1881.

(2.) *Zinc.* The most refrangible rays in the spectrum of this metal were measured by M. Cornu, but they do not appear in the prints of these photographs, being too feeble; their feeble character being due to the absorptive power of the six feet of air through which the rays passed.

(3.) *Cadmium.* The lines of this metal, which were first measured by M. Mascart, have since been re-measured by M. Cornu. The basis of M. Mascart's measurements was the number of Fraunhofer for the line D—namely, 588·8. M. Cornu took measurements from the most refrangible of the D lines with the wave-length 588·89. M. Cornu's numbers are the following:—*No.* 9, 360·9; *No.* 10, 346·68; *No.* 11, 340·15; *No.* 12, 324·7; *No.* 17, 274·77; *No.* 18, 257·23; *No.* 22, 232·18; *No.* 23, 231·35; *No.* 24, 226·55; *No.* 25, 219·45; *No.* 26, 214·41. This last is not visible in these photographs, the other two adjacent lines have wave-lengths of 324·8 and 325·8.

(4.) *Aluminium.* The two continuous and extended lines near the strong air line *No.* 8 in the spectrum of Cadmium 398·56 (Mascart) are figured in M. Cornu's map. Their wave-lengths are 396·06 and 394·33. Two other lines similar in character, but more refrangible, appear to be identical with a pair with wave-lengths 309·15 and 308·5. These lines are about in the same position as a faint triplet b″ in the Magnesium spectrum, the least refrangible ray of which has a wave-length of 309-6. (Cornu).

(5.) *Indium.* The two least refrangible lines in the blue and violet have been measured by Thalen. Wave-lengths 450·9 and 410·1.

(6.) *Thallium.* (7.) *Copper.* (8.) *Silver.* (9.) *Mercury.*

Plate xvii.

(10.) *Graphite.* The spectrum of Graphite contains at most only twelve of the shortest possible lines or "dots." Eleven of these are visible in the prints when examined with a powerful lens.

(11.) *Tin.*

(12.) *Lead.* The least refrangible line is visible, and has been measured by Kirchoff; wave-length 438·7 to 438·6.

(13.) *Tellurium.* (14.) *Arsenic.* (15.) *Antimony.* (16.) *Bismuth.*

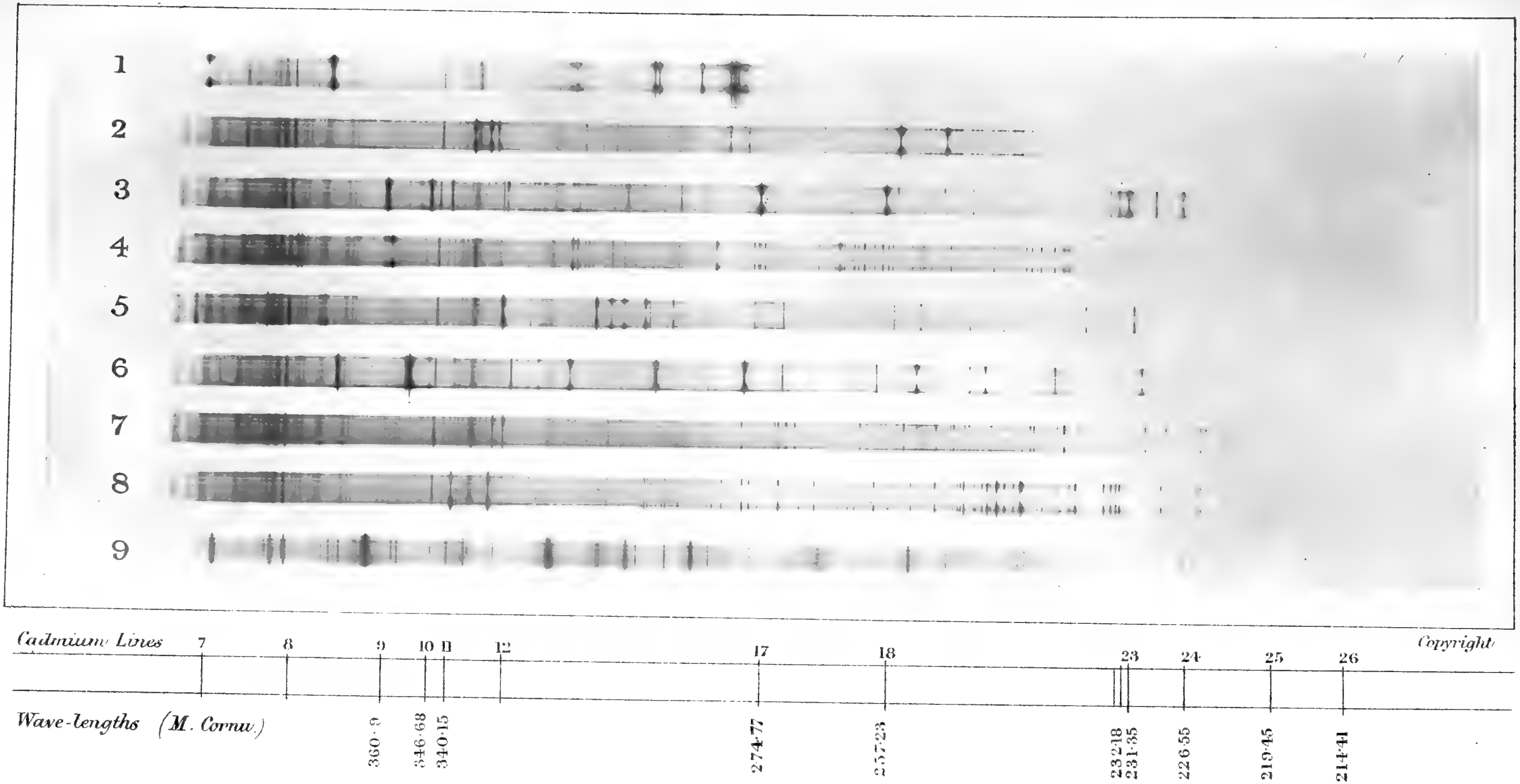
Plate xviii.

(18.) *Iron.* The spectrum of this element contains over 600 lines visible in the original photographs, exclusive of air lines. The total number of lines belonging to the metal, and capable of production with a one prism spectroscope, cannot, however, be fewer than 1,000, since, by the use of more sensitive plates, spectra increased by one-half in length may be photographed, the new region being crowded with lines.

(19.) *Nickel,* 225 lines. (20.) *Cobalt,* 490 lines.

(21.) *Palladium,* 333 lines. (22.) *Gold.*

(23.) A repetition of the *Aluminium* spectrum.



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(PLATE XVIII)
Cd. Cadmium.
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21. Palladium.
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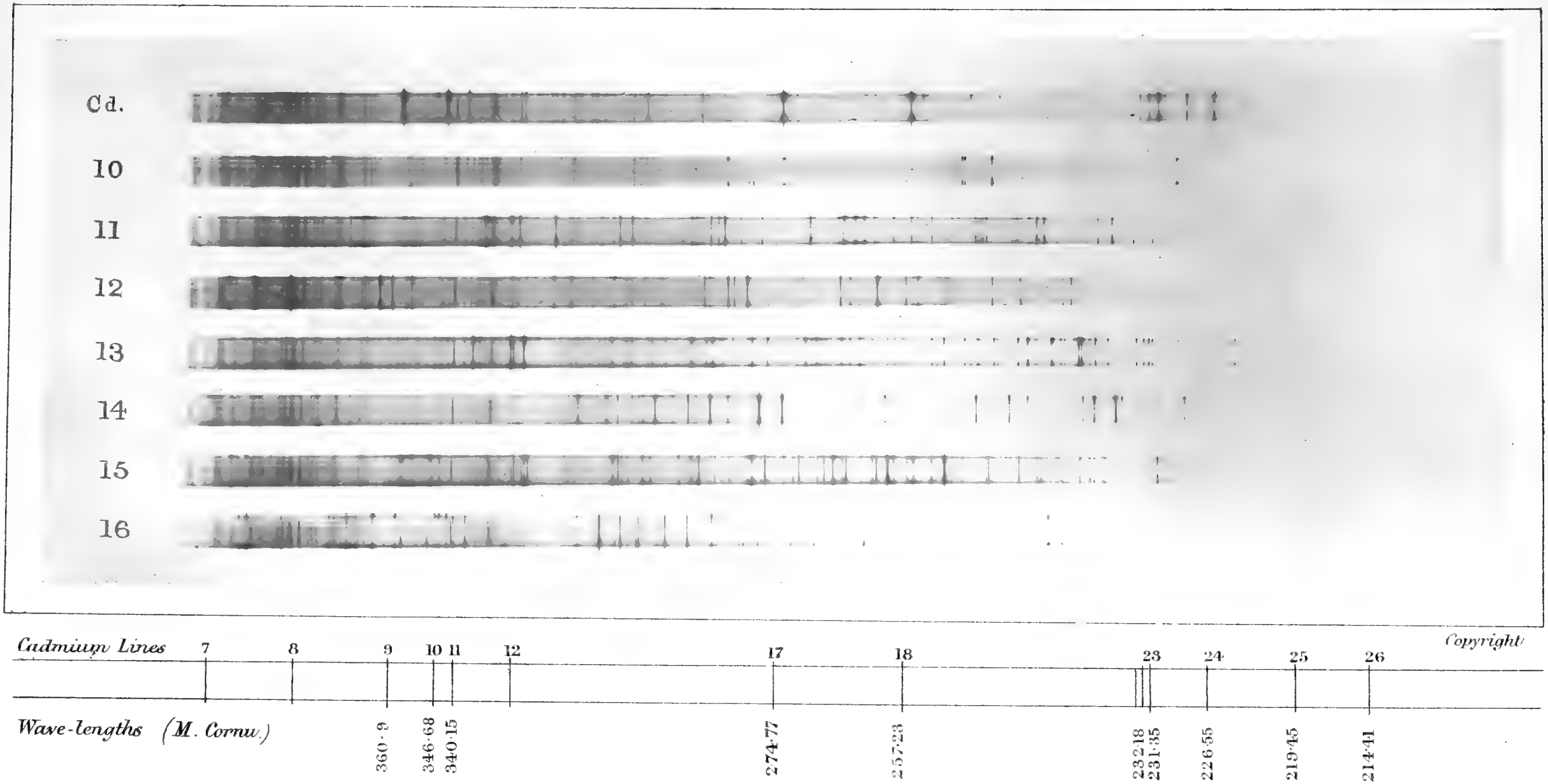
23. Aluminium.

W.N. Hartley photo.
Woodbury Type Co.



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W.N Hartley photo.
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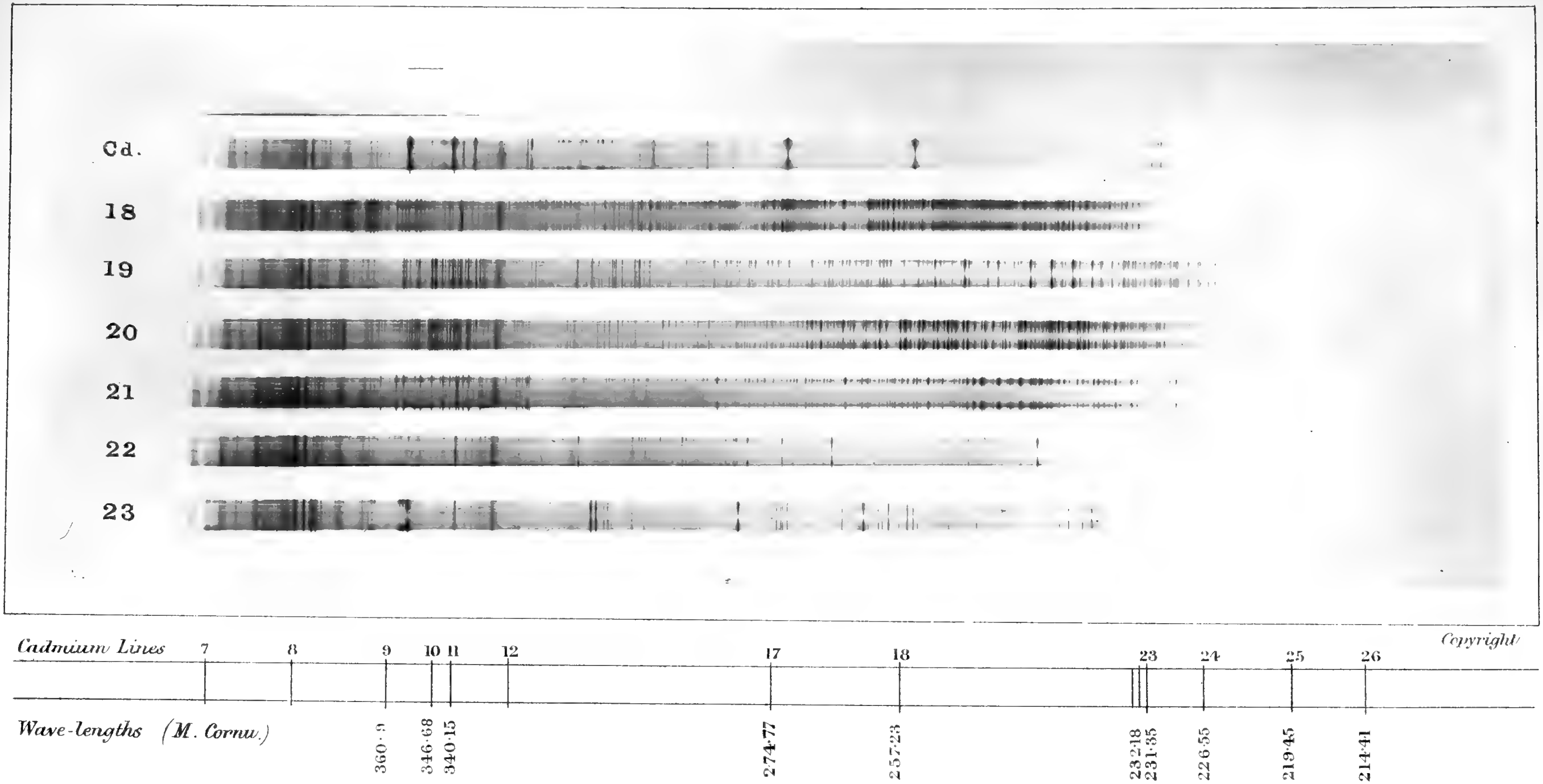

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(Already Published.)

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[AUGUST, 1882.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I (SERIES II.)

XVII.—*Notes on the Physical Appearance of the Comets b and c,* 1881, *as observed at Birr Castle, Parsonstown, Ireland.* BY THE EARL OF ROSSE AND OTTO BOEDDICKER, PH.D.—PLATE XIX.

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XVII.—NOTES ON THE PHYSICAL APPEARANCE OF THE COMETS *b* AND *c*, 1881, AS OBSERVED AT BIRR CASTLE, PARSONSTOWN, IRELAND. By Otto Boeddicker, Ph.D. Plate XIX.

[Communicated by the Earl of Rosse.]

Owing to the vacation, and afterwards to the unfavourable weather, it was not until July 20th that the first observation of Comet *b*, 1881, could be obtained, and only on five subsequent nights was it possible to continue observing. Thus altogether six drawings of, however, not at all equal value were made. Comet *c* could be observed on one night only, as, when clear nights again set in, it sank too low early in the evening, and did not rise again until morning twilight.

All the observations were made with the reflector of 3 feet aperture, the speculum of which had been recently repolished.

The following remarks on the appearance of the comets were taken from the observing book. The time referred to is mean time Greenwich: the powers used were 144 and 216.

Comet *b*, 1881.

Pl. XIX., Fig. 1. *July* 20, 11h. 45m.—about 13h. 30m. Very clear.

No detailed structure at all perceptible. Nucleus very bright and very well defined. Brightness from the nucleus very suddenly decreasing, tail rapidly and considerably fainter. The nebulosity in the coma (towards the apex) seems to be brightest. I thought sometimes I saw a darker space in the tail behind the nucleus.

Pl. XIX., Fig. 2. *July* 22, 10h. 25m.—about 11h. 25m. Partially clear.

Nucleus very bright, extended towards both sides, as shown in drawing. Tail rather suddenly fainter. Coma almost uniformly bright. Behind the nucleus towards the tail decidedly a darker lane (like a shadow, only broader than the nucleus)*; hardly any trace of it visible further on in the tail. When the telescope was moved the coma appeared more like a fan, but when the image was kept steady this was not very, if at all, perceptible. About 11h. 25m. Difference of light between "shadow" and tail very slight. No structure in coma any longer visible. Sky begins to be covered with a thick haze.

In the drawing the contrast between the "shadow" and surrounding nebulosity is not quite strong enough.

* Whenever this dark space has been observed it will be referred to as the "shadow" in the following notes.

Pl. XIX., Fig. 3. *July* 24, 11h. 47m.—about 12h. 20m. Squally. Heavy cirro-strata continually passing. Comet visible for short intervals only.

Nucleus very bright and very well defined, extended towards the apex, certainly not towards the sides, looks rather like a fan. "Shadow" visible, contrast between it and the tail not very strong, no trace of it in the tail a little further from the nucleus. Tail very rapidly much fainter. The nucleus projects into the "shadow" as in drawing; the fan-like appearance very decided. Light from nucleus towards coma very suddenly decreasing. The light-fan terminates on the following side more abruptly than on the other; it seems sometimes to consist of different rays.

Pl. XIX., Fig. 4. *July* 27, 10h. 30m.—about 11h. 0m. Moderately clear, then overcast.

The comet is very much like the drawing of July 20, but considerably fainter and smaller. Nucleus very well defined. "Shadow" extremely faint. Coma very gradually less bright; no light-fan, more a general halo. Radius of coma rather small. A segment seems sometimes to be cut out of the apex.

Pl. XIX., Fig. 5. *July* 31, 9h. 50m.—about 10h. 50m., 11h. 50m.—12h. 20m. Very clear. Sky at first very bright.

Comet considerably fainter. "Shadow" indistinct, but perceptible, nucleus projecting into it. Traces of a light-fan on the preceding side, terminating rather abruptly on the following one. There seem to be bright streamers in the fan. One side-ray towards the following side as in drawing; coma as if interrupted by a darker sector. Light of coma very gradually fainter. Side-ray much fainter than the preceding fan. 12h. 0m. All the details rather indistinct, yet certainly visible. Tail rapidly less bright, side-ray very faint. "Shadow" hardly defined, more like a gradual decrease of brightness as on July 20.

Pl. XIX., Fig. 6. *August* 1, 10h. 30m.—10h. 50m. Sky very hazy.

Nucleus very well defined, very sharp. Not much detail visible. Traces of a fan. Traces of the "shadow," the latter without any sharp outline; outline of fan likewise very indistinct. Radius of coma rather small. A star very well visible through the comet, the nucleus decidedly brighter.

Comet *c*, 1881.

Pl. XIX., Figs. 7 and 8. *August* 19. Clear; hazy clouds passing.

9h. 15m. Nucleus well defined, and very bright. From it something like a light-fan. Light towards apex (near nucleus) brighter. Tail bright, but considerably fainter than the nucleus; in the tail behind the nucleus a dark line.

9h. 35m. No structure visible. General fan-like halo. Fan not very sharply defined.

9h. 50m. Nucleus projecting into the "shadow," which is rather faint. Light on both sides of the apex brighter; this sometimes very distinct. The fan lies sometimes a little towards the preceding side. The following part of the "shadow,"

(next to nucleus) darkest, There seem to be more parallel dark stripes in the tail (Figure 7).

10h. 0m. Slight traces of an inverted fan (towards the tail) visible as in drawing. Hardly any trace of the "shadow"-line in the tail (Figure 8).

10h. 40m. No sharp "shadow"-*line*, but general shadow (broader and less sharply defined). The tail seems sometimes to terminate more abruptly on the following side.

11h. 35m. The details, as at 9h. 50m., very well defined. No "shadow"-line.—

Though the above remarks contain everything necessary for the explanation of the Plate, still it will be useful to state, in a few words, the chief results suggested by them. We begin with Comet *b*, Pl. XIX., Figs. 1–6.

All the observations show in common a rapid decrease of brightness from the nucleus towards the coma as well as towards the tail. The light on the side of the nucleus directed towards the sun—in the coma—is brighter throughout than on the opposite one; the dark part on the tail-side appears sometimes rather well defined (as especially in Fig. 2), but never like a sharp, straight line. Its traces disappear rapidly a little further from the nucleus. The apex of the coma terminates in an uninterrupted parabolic curve, with one exception (July 27), where traces of a dark segment cut out of it have apparently been observed. No great stress, however, can be laid on this observation, as it has obviously been made under rather unfavourable circumstances. The radius of the coma, for instance, appeared "rather small" (as also on August 1), a necessary effect of a hazy sky.

Considerable changes of the comet are only shown in the shape of the nucleus and the light proceeding from it, where the following different phases can be discerned :—

a. Nucleus round, sharp, and well defined, surrounded by a bright structureless halo. (July 20, and perhaps 27.)

b. Nucleus elongated towards both sides, the light in the coma perhaps like a broad fan. (July 22.)

c. Nucleus extended towards the apex like a fan, projecting into the "shadow." (July 24.)

d. Nucleus round, and a much fainter light-fan proceeding from it. (August 1.) This fan consisting of different rays. (July 31.)

The two last phases differ obviously in the degree of brightness only, and the figure of the nucleus in the second one (*b*) is probably nothing but a very wide opening of the light-fan.

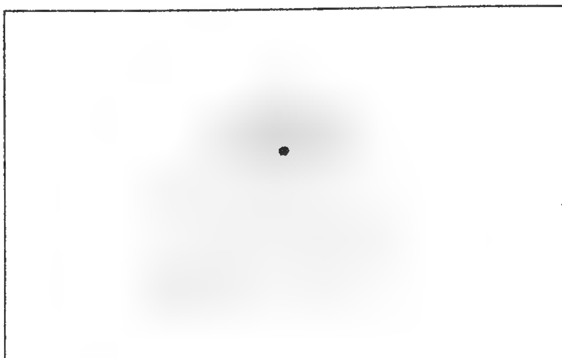
The situation of this fan-like emanation of light from the nucleus with reference to the central line of symmetry of the whole comet changes considerably, as will be seen by a comparison of Figs. 3, 5, and 6. Its shape is not at all symmetrical, as shown by Fig. 3, where the following side terminates much more abruptly, and by Fig. 5, where it consists of one broader part lying towards the preceding side, and a fainter ray towards the following one. The darker sector between them is

perhaps equivalent to the "dark segment" mentioned in the remarks belonging to Fig. 3. Finally it may be mentioned that there were certainly not even traces of concentric rings visible in the coma, as have been frequently observed in other comets.

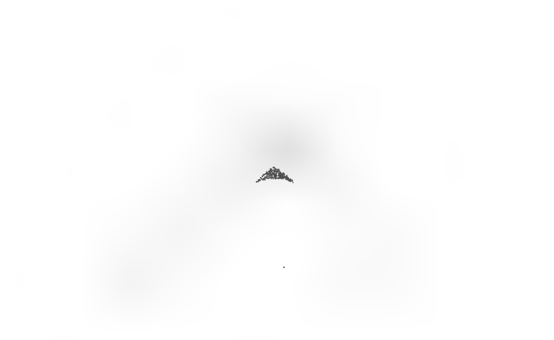
On searching for drawings of other comets, which might be compared with mine, I did not find any which bear a greater resemblance to them than Bessel's drawings of Halley's comet, in the "Astronomische Nachrichten," of February, 1836, (Vol. XIII.).* The similarity between the two comets, as represented by the drawings is so great, that Bessel's description is of good service in explaining the different features of Comet *b,* 1881. The only difference between the two series of drawings is, that Bessel observed throughout the dark segment cut out of the coma, whilst he does not record any instance of the light-fan ("Ausströmung") consisting of different rays, as in my drawing Fig. 5. The different situations of the light-fan in my drawings mentioned above prove, when compared with Bessel's description, that Comet *b* showed the oscillating motion of the light-conoid proceding from the nucleus ("die drehende oder schwingende Bewegung des ausströmenden Lichtkegels") rather strongly developed, and it is to be hoped, that this point in particular may be more thoroughly investigated by means of drawings of other observers.

Not much is to be derived from the two drawings of Comet *c* (Pl. XIX., Figs. 7 & 8), some striking differences from the preceding comet are, however, set forth by them, which deserve mention. The radius of the coma was smaller, the nucleus was not quite so well and sharply defined (this is not sufficiently shown in the plate), and the light, proceeding from it, more gradually decreasing. The coma, equally without concentric rings, was interrupted by a darker segment in the apex, suggesting nebulous matter flowing fountain-like from the nucleus towards the tail. The part behind the nucleus—the "shadow"—was shaded off to a sharp dark line, which, however, became invisible, or disappeared, during the observation. On the whole, the description proves that the comet was subject to rapid changes on the night of the 19th August, since the different statements can hardly be attributed to atmospheric influences only. The most interesting and remarkable feature is the "inverted fan" in drawing Fig. 8, representing a direct emanation of nebulous matter from the nucleus towards the tail—another point, where more light is to be expected from a comparison with other observations.

* Reprinted in Johann Carl Friedrich Zöllner, Ueber die Natur der Cometen.

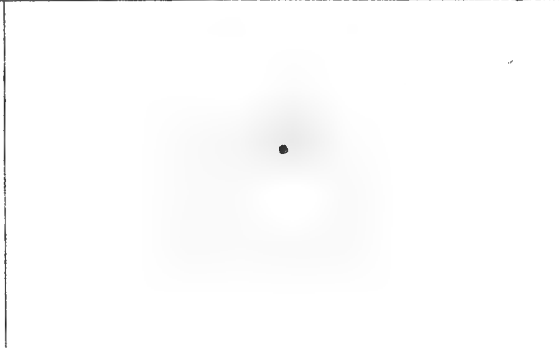


1. Comet *b* 1881, July 20 $11^h\ 45^m$

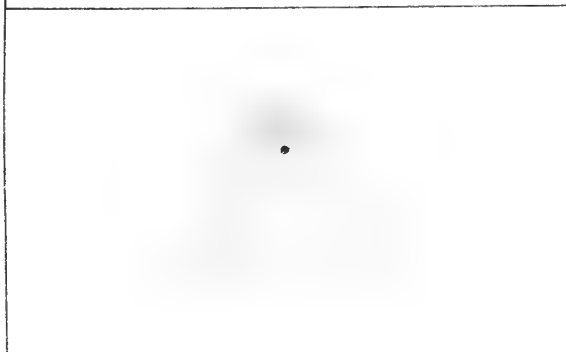


2. Comet *b* 1881, July 22 $10^h\ 25^m$

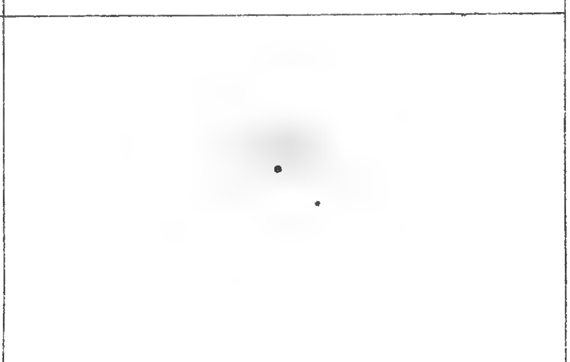
3. Comet *b* 1881, July 24 $11^h\ 47^m$



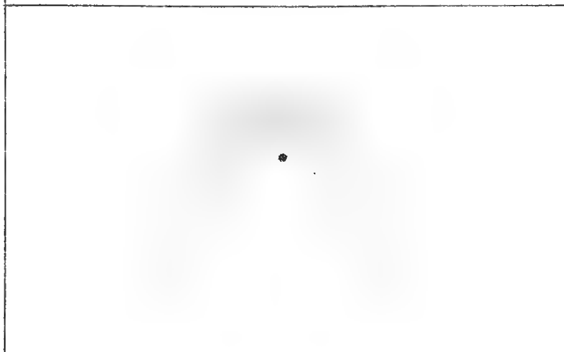
4. Comet *b* 1881, July 27 $10^h\ 30^m$



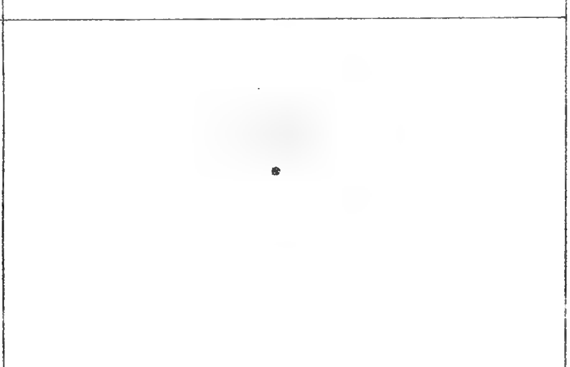
5. Comet *b* 1881, July 31 $9^h\ 50^m$



6. Comet *b* 1881, Aug. 1 $10^h\ 30^m$



7. Comet *c* 1881, Aug. 19 $9^h\ 50^m$



8. Comet *c* 1881, Aug. 19 $10^h\ 0^m$

Otto Boeddicker del. Fredk Dangerfield Lith London 2918

TRANSACTIONS (NEW SERIES).

VOLUME I.

(Recently Published.)

PART.

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18.—On the Laurentian Rocks of Donegal, and of other parts of Ireland. By EDWARD HULL, LL.D., F.R.S., &c., Director of the Geological Survey of Ireland. Plates XX. and XXI. (February, 1882.)

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[February, 1882.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XVIII.—*On the Laurentian Rocks of Donegal, and of other parts of Ireland.* By Edward Hull, LL.D., F.R.S., &c., *Director of the Geological Survey of Ireland.*—Plates XX. and XXI.

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XVIII.—ON THE LAURENTIAN ROCKS OF DONEGAL, AND OF OTHER PARTS OF IRELAND. By EDWARD HULL, LL.D., F.R.S., &c., DIRECTOR OF THE GEOLOGICAL SURVEY OF IRELAND. PLATES XX. AND XXI.

[Read 21st November, 1881.]

INTRODUCTORY.

The following is an account of the more important papers dealing with the formations of Donegal, which constitute the chief topic of the present paper:—

Mr. Robert H. Scott, F.R.S., in a paper "On the Granitic Rocks of Donegal,"* describes the three granite districts represented on Griffith's Geological Map—that of Barnesmore, of Ardara, and of the large tract ranging from Lettermacward to Glen, along the valleys of the Gweebara and Glenveagh rivers. The examination, in which he was assisted by the Rev. Professor Haughton, was restricted to the south-western portion of the county. He states his opinion that "the typical Donegal granite," as a whole, "presents no appearance of being a purely igneous rock, the evidence, in fact, pointing to a metamorphic origin for it." Again he says, "it is thoroughly gneissose in its character, and lies in thin beds corresponding to the bedding of the stratified rocks of the country."

Mr. Ethelstone H. Blake, in a paper "On the Primary Rocks of Donegal,"† describes sections of the granitic and associated rocks, which he considers assume almost everywhere a vertical position. He agrees with Mr. Scott in considering the Donegal granite not to be of igneous origin.

Mr. R. H. Scott, in a paper "On the Granitic Rocks of Donegal, and the minerals therewith associated," being a continuation of his former communication, gives an account of observations made during a tour, in company with Mr. R. Byron, in the south and west of the county, and afterwards with Professor Jukes; he also acknowledges his obligations to Mr. Harte, County Surveyor. He considers the igneous rocks of Inishowen to be undoubtedly contemporaneous with the sedimentary rocks of the district, and appeals to the sections along the coast between Buncrana and Carndonagh. The typical granite is everywhere stratified with an eastward dip, and becomes more gneissose as you approach the edge of the district. A very complete catalogue of the minerals of county Donegal and their localities is appended.

* Journal Geol. Soc. Dublin. Vol. IX., pp. 285–294. † Journal Geol. Soc. Dublin. Vol. IX. p. 295.

The late Professor Harkness, "On the Metamorphic Rocks of the North of Ireland."* In this paper the author gives an account of the succession of the rocks between Malin Head and Inishowen Head, which, with the succeeding chloritic schists, he considers the Irish representatives of the strata of the Grampians.

Mr. R. H. Scott, "On the Granitic Rocks of Donegal, and the minerals associated therewith."† In this paper the author offers evidence that the typical Donegal granite, with its associated strata of limestone, &c., were never in a melted condition, but were originally stratified rocks, which have undergone metamorphism. He considers there is a close relationship between these rocks and the granites of Norway.

Professor Harkness, "On the Rocks of portions of the Highlands of Scotland and their equivalents of the North of Ireland."‡ In this paper the author deals with the age of the quartzites, limestones, and schists of the promontory of Inishowen, which he identifies with the beds of the Scottish Highlands, south of the Caledonian Canal, lately shown to be of Lower Silurian age through the researches of Sir R. I. Murchison.

Dr. T. Sterry Hunt, F.R.S., "On the Chemical and Mineralogical Relations of Metamorphic Rocks."§ The author, after discussing the origin of these rocks, and describing the metamorphic groups of North America, adds—"Many of the rocks of Donegal appear to me lithologically identical with those of the Laurentian period; while the serpentine of Aghadoey, containing chrome and nickel, and the andalusite and kyanite schists of other parts of Donegal, cannot be distinguished from those which characterize the altered palæozoic (Lower Silurian) strata of America." This paper contains the first intimation of the Laurentian age of the gneissose rocks of Donegal.

Rev. Dr. Haughton, F.R.S., "On the Granites of Donegal."‖ In this paper the author describes the range of the granites and their mineral constitution. He states that the granite of Donegal appears to be interstratified with the quartz rock, mica slate, and limestone, with which it is associated; but that it is probably subsequent to them in age, and in its central portion is, perhaps, of igneous origin.

Elaborate analyses of a number of specimens are given, as also tables of joint planes and descriptions of sections.

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* British Association Reports, 1860. Trans. of Sections, p. 79.

† British Association Reports, 1861. Trans. of Sections, p. 131.

‡ Quarterly Journal Geol. Soc. London. Vol. XVII., p. 256 (1861).

§ Journal Geol. Soc., Dublin. Vol. X., p. 85.

‖ Transactions Royal Irish Academy. Vol. XXIV. Part 5.

PART I.

Preliminary Statement.

With a view of determining the geological age and relations of the old gneiss of Donegal, I made an examination of the line of boundary between it and the metamorphosed Lower Silurian beds, as very well laid down on Griffith's Geological Map of Ireland, during the early part of last summer, in which examination I had the assistance of Mr. R. G. Symes, F.G.S., Mr. S. B. Wilkinson, and, for a part of the time, Mr. J. Nolan, officers of the Geological Survey.* We commenced our observations at Fintown, west of Stranorlar, and continued them, with but slight intervals, all the way to Lough Salt (correctly L. Alt) near Glen, at the north end of the gneissic tract. We also examined the N.W. boundary, from Creeslough to Dunlewy and Gweedore, at several points, and also made a complete transverse of the gneissie district from the Atlantic coast at Dunglow, by Doochary, Glenleheen Bridge, and Fintown, to Letterkenny. This exploration— extending over ten or eleven days—enabled us to arrive at the following conclusions :—

First.—That the gneissose series of Donegal is unconformably overlaid by metamorphosed Lower Silurian beds along the eastern and southern boundaries.

Second.—That the similarity in physical characters of the gneissose series, and indentity of stratigraphical position, with the "fundamental gneiss" of parts of Sutherlandshire and Rosshire, affords a presumption that, like the latter, it is of Laurentian age.†

Third.—That the north-western boundary of the gneissose series is a large downcast fault which ranges from the entrance to Barnesbeg Gap, near Creeslough, to the eastern base of Errigal at Dunlewy ; and that the boundary at Gweedore is probably also a fault transverse to the former.

Fourth.—That there is no evidence of the presence of any beds representing the Cambrian series ; and, therefore, that the unconformity above referred to represents a great hiatus, such as occurs in the series of formations in the districts of Ben Arkle and Foinaven in Sutherlandshire, where the Lower Silurian quartzites rest directly on the fundamental gneiss ; the Cambrian sandstones having here disappeared.

Description of Sections, &c.

I now proceed to give some account of the two great series of unconformable formations of North-west Donegal. This account need only be brief as previous authors have so fully described them.

* This examination was official, and made with the assent of the Director-General.

† It will, probably, always be impossible to demonstrate that the British rocks lying below the Cambrian beds are of the same age, and strictly representative of the Laurentian beds of Canada, but I agree with Professor Ramsay in the opinion, "that the presumption that they are of Laurentian age is very strong."—Phys. Geol. of Gt. Britain. 5th Edit.

(1.) *Lower Silurian Series.*—The schists, quartzites, and limestones which are represented on the geological maps as ranging in a south-westerly direction from the Atlantic coast, through Inishowen, to the shores of Lough Swilly, and re-appearing on the opposite coast, have been shown by Professor Harkness to be representatives of the beds of the Scottish Highlands south of the Caledonian Canal, which re-appear in Sutherland and Ross resting unconformably on the Cambrian sandstones and conglomerates.* Harkness accepts the interpretation, given by Sir R. I. Murchison, of the Lower Silurian age of these beds, and, therefore, arrives at the conclusion that the Donegal beds are likewise of Lower Silurian age. No one who has examined the Inishowen beds from the shores of L. Foyle to that of L. Swilly, and compares them with those of the North Highlands between Lochs Broom and Erribole can fail, as it seems to me, to recognise the soundness of this view, and it is one in which, with a personal knowledge of both districts I fully concur.† In both districts there is to be found a somewhat similar succession of quartzites, schists, and limestones, overlaid by a great series of chloritic and micaceous schists; the chloritic schists being, however, much more fully developed in the North of Ireland, particularly in the counties of Derry and South-east Donegal, than in the Scottish Highlands. Making allowances, however, for changes due to geographical space, there is a remarkable similarity in the characters of the strata in the lower portion of the series in both districts; but the highly metamorphosed character of the limestones of Donegal, has, hitherto, rendered it impossible to obtain traces of fossil forms, such as have been recognised in the Durness limestone of Scotland.

It is not my intention to give a detailed description of the Lower Silurian Series of Donegal after what has already been written. The general succession of the lower beds is shown in the tongue of land lying between Mulroy Bay and Lough Swilly, of which a generalized section is given.‡ (Plate XX. Fig. 1.)

These beds cross Mulroy Bay, and rise into the escarpment of Lough Salt, which terminates westward against the gneissose hills of Crockmore, south of Glen, where we obtained the clearest evidence of the unconformity of this series to that of the gneiss itself. The section here is as follows—in descending order:—

Section of Lower Silurian Beds.

1. Quartzites; forming the ridge above the south shore of L. Salt (L. Salt Mountain 1,546 ft).
2. Beds of hornblendic diorite.
3. Beds of quartzite and quartz-schist.
4. Blue limestone—about 50 feet thick.
5. Beds of schist and quartzite.
6. Lower thin bedded limestone, about 100 feet thick, forming the escarpment S. of L. Greenan.
7. Schists, &c.

* Quart. Journ. Geol. Soc. Vol. XVII. (1861).

† In the spring of 1880, the author examined the district of the North Highlands, above referred to, in company with Mr. R. G. Symes, and under the guidance of Professor Geikie, Director of the Geological Survey of Scotland. An account of this visit is published in the Scientific Proc. Roy. Dub. Soc. Vol. III.

‡ This section was made in 1875, during a previous visit.

The above series has a thickness of over 2,000 feet, and is abruptly truncated at the margin of the old gneissose series between the entrance to Barnesbeg Gap and L. Greenan. To this I shall have occasion to return. Both above and below the Lough Salt beds there is a great series of schists, quartzites, limestones, with beds of hornblende schist, passing into diorite, which likewise terminate at the margin of the old gneissose series; the general dip being S.E.

(2.) *The Laurentian Gneissose Series.*—The Donegal gneiss has been correctly described by Dr. Haughton, and Mr. R. H. Scott as really a metamorphosed stratified formation. They also show that it contains beds of crystalline limestone or marble, with which several minerals, such as sphene, idocrase, and garnet, are often associated.* They also point out that along with the foliated and bedded gneiss, there is found a massive granite, in which planes of foliation are not apparent. This variety occurs at Dunglow and elsewhere. It is uncertain whether or not this latter variety belongs to the gneissic series. From what I saw of it, I am inclined to regard it as the more deeply seated portion of the original great formation, in which the metamorphic action has given place to actual fusion. Leaving this question (which is not material) it may be stated that, as we ascend in the series, the foliated character becomes more apparent, and the upper beds which occur along the south-eastern margin are largely interstratified with hornblendic and micaceous schists, giving rise, as in the hills about the eastern entrance to Barnesbeg Gap and Crockmore, to successive ridges, formed by the solid beds of gneiss divided from each other by beds of softer schist.

The typical characters of the gneissose series are well shown in Barnesbeg Gap; also, in the hills bordering the Bulhalla and the Owenwee rivers, and in the valley east of Doochary bridge, as well as in many other sections. The rock consists of red orthoclase, often in large crystals porphyritically distributed, a little grayish oligoclase, green and black mica, and quartz. It is generally distinctly foliated, though massive, and is traversed by numerous veins and dykes of pegmatite, consisting of red orthoclase and quartz, with very little mica. Seen on a large scale, the predominating colour is light red, but there are places where this rich colouring fades into gray.

The upper members of this great series, as far as they are exposed to view before being concealed beneath the Lower Silurian beds, consist of numerous interstratifications of red and gray gneiss, hornblendic and micaceous schist with garnets, and at rare intervals bands of crystalline limestone, with sphene, idocrase, and garnet, or with pseudomorphs of idocrase after garnet, as pointed out to me by Dr. W. Frazer.† These beds are laid open along the road from Glenlehene bridge

* Dr. Frazer, M.R.I.A., accounts for the peculiar form of the idocrase crystals as found at Annagarry and elsewhere, which is that of garnet, by suggesting that the crystals are pseudomorphs after garnets.

† Sphene, idocrase, garnet, &c., are recorded by M. J. Durocher as abundant amongst the beds of limestone of the old gneiss (Urgneiss) of Sweden, Norway, and Finland, which is presumably of the same age as that of Scotland and Donegal.—"Ann. des Mines," Tome 15, 4^{me} Ser., p. 181.

to Fintown, where they show a thickness of over a thousand feet. Beds of white and blue crystalline limestone may be distinctly seen associated with, not only the upper, but the central gneissose series, in the quarry above Glenlehene; also at Ardnawark, near L. Salt, at Dunlewy, and Annagarry. The minerals associated with these calcareous bands are described by Mr. Scott.*

It is impossible to estimate with any approach to accuracy the thickness of the old gneissose series of Donegal. Even if we assume the gray and reddish granite, destitute (or nearly so) of foliation, which occurs at Dunglow, as the lowest portion, in no place do we meet with the uppermost beds, as the overlap of the Lower Silurian series along the eastern margin conceals them from view. The beds generally have a high dip, from 60°–80°, and have a strike parallel to that of the great central glen of the Gweebarra and Owencarrow rivers, which traverses the whole gneissose region from Gweebarra Bay on the south-west to Glen on the north-east.

(3.) *Unconformities.*—There are two forms of unconformity observable between the gneissose series and the Lower Silurian beds. If we take the south-eastern boundary of the two formations as a datum line, there exists, in fact, an obliquity on the part of the gneissose beds on the one hand, and of the Silurian beds on the other, to this line.†

(*a.*) As illustrating the nature of the former, it may be observed that different portions of the gneissose series are in contact with the boundary line in different places. Thus, commencing at the northern extremity of the district at Glen, we find the central beds of red gneiss in contact with the Silurian quartzites, &c., as may be observed in the Glen river, and at the hamlet of Ardnawark, where the Silurian beds repose on massive red gneiss with crystalline white marble. On the other hand, south of Crockmore, also near the entrance to Barnesbeg Gap, and around L. Acrobane, higher beds of the gneissose series intervene between the Silurian boundary and the central beds of red gneiss, consisting of alternating schists and beds of white granite, or gneiss, of at least 1,000 feet in total thickness. The boundary of the solid red gneiss is well shown by the abrupt rise of the hills west of the L. Gartane valley, which is presumably occupied by the softer upper schistose beds, and extends to the junction of the Owenwee and Bullaba rivers. About a mile up the former of these streams is a fine cascade, where the red massive gneiss is well laid open, dipping to the S.E. below the upper series which forms

* A similar band of limestone occurs in the Laurentian gneiss of L. Maree, in Scotland, and is described by Sir R. I. Murchison, and Professor Geikie in terms which might be applied to the limestones of the old gneiss of Donegal. On both sides of the torrent Foulish it occurs as "a snow-white saccharoid marble."—Quart. Journ. Geol. Soc., Vol. XVII., p. 177.

† I admit that the term unconformity is here used in a very uncommon sense, and is applied to the outcrops of the surfaces of stratification, and the junction of the two formations. The two phenomena in question are independent, and, therefore, corroborative evidences of unconformity in the ordinary sense.

the ridge of Brallanmore. Some distance further south, however, in the Fintown district the red gneiss is seen in the stream above Mill Bridge almost in contact with Lower Silurian quartzite, which descends from the ridge of Scraigs with a strong easterly dip.* About a mile still further southwards, the red gneiss is overlaid by several hundred feet of the schistose beds, not present in the former locality, before the Silurian beds set in.

Thus it would appear, if the above statements are correct, that the floor upon which the Lower Silurian beds were originally deposited consisted sometimes of higher, sometimes of lower, members of the older gneissose series, according to the extent of the denudation which had taken place antecedently over different portions of the whole area. Such conditions would be quite in accord with observations over the north-western Highlands of Scotland, where the Cambrian or Silurian beds, as the case may be, repose on very different portions of the gneissose series according to locality; and this forms one of the points of analogy between the geological structure of the two regions.

(*b*). As illustrating the second case of unconformity, namely, the obliquity of the Lower Silurian beds to the boundary line of the Laurentian, we have the clearest evidence of such conditions in the Lough Salt district. This obliquity is suggested by the position of the strata as represented on Griffith's map, and is referred to by Mr. Scott as an apparent unconformity.† It was the study of Griffith's map which first suggested to my own mind the unconformable relations of the two sets of strata, and the probable Laurentian age of the lower series.

On the 2nd of May, accompanied by Messrs. Symes and Wilkinson, we made a careful examination of the rocks lying on either side of the boundary line along the Glen River and Lough Salt range. Our first section showing the junction is represented in Figure 2, Plate XX., where in the bed and banks of the stream we found laminated gray shales, nearly flat, resting tranquilly upon an old shelving floor of granitoid gneiss belonging to the Laurentian series.

This section was of much interest to us as affording corroborative evidence that the junction of the two series of beds is not, in this district, a fault or dislocation.

Further up the stream at Ardnawark we found beds of white saccharoid marble overlying massive reddish granitoid gneiss, and penetrated by pegmatite veins. This was the first occasion in which we had seen limestones in the Laurentian series.‡

A little further south the structure of the country becomes conspicuous by the

* Mr. Symes suggests that the boundary may here be a fault, but the evidence is not sufficient to enable us to form a definite opinion; the case is one of an unconformity, or a fault, or possibly, of both combined.

† Mr. Scott states that at Barnesbeg Gap, S. of the L. Salt district the limestone is apparently unconformable to the typical granite or gneiss, and full of garnets and idocrase.

‡ A slight cross-fault seems to occur here.

tread of the hills and valleys. Looking towards the south, we see the quartzite escarpment of L. Salt Mountain bending more and more towards the east; while on looking eastward we see the escarpment of Crockmore, consisting of alternating beds of gneiss and schist belonging to the Laurentian series, ranging very much in the same line of strike. It became evident to us that the two groups here impinge one against the other; and we determined to devote the greatest care to the determination of the nature of the boundary line between them.

The succession of the Lower Silurian series of the Lough Salt* ridge is indicated in Figure 3, Plate XX., which is also intended to show the nature of the junction between the two groups. The summit of the ridge consists of quartzite, below which there is a series of beds consisting of schists, limestones, quartzites, and hornblendic rocks of over 1,000 feet in thickness.

Below these are also other beds of quartzite, &c.—which crop out in the direction of Glen—but are concealed at this spot by the overlap of the upper beds along the shelving Laurentian bank. This will be better understood by a reference to Figure 4, Plate XX., which is drawn to correspond with the section (Fig. 3, Plate XX.)

On reaching the deep depression of L. Salt, we considered it desirable to fix upon a special bed, and trace it westwards, so as to observe the nature of its contact with the gneissose series. For this purpose we selected a bed of blue, laminated, limestone (No. 2) about 100 feet in thickness, which forms an escarpment overlooking L. Greenan. Following along this bed for a few hundred yards south of the lough—and carefully hammering every projecting piece of rock—we, at a certain point, lost the limestone, and found ourselves amongst a series of strong micaceous schists which we presently recognised as belonging to the gneissose or Laurentian series, as shown at the entrance to Barnesbeg Gap, only a short distance further south. Crossing the strike in a southerly direction, we found the succeeding beds of quartzite, hornblende rock and limestone, successively terminating at the margin of the same beds of schist. Then the obliquity of the two series became evident; and, as we satisfied ourselves by observations made close to the junction that there is no evidence of disturbance or of fracture, we concluded that there is here one of the most remarkable cases of unconformable overlap to be found in any district of the North of Ireland.†

From the evidence obtained in the district of Glen and L. Salt, as well as at other points along the S.E. margin of the two formations, we came to the conclusion;—that the Lower Silurian strata had been deposited against the flanks of a shelving bank of the old Laurentian rocks while it was being depressed beneath the waters of the sea. Subsequent disturbances and denudation have brought to light successive beds of various geological horizons along the Laurentian

* This, as I was informed by the Rev. Dr. Allman, Rector of Kilmacrennan, is a corruption for L. Alt.

† The section in the Glen River (Fig. 2, Plate XX.) also shows that the boundary is not a fault.

margin. Thus it is probable that the quartzite of L. Salt Mountain is over 2,000 feet higher in position than that which comes in contact with the old gneiss at the village of Glen, while still higher beds terminate against the gneiss further south in the neighbourhood of the Owenbeg and Owenwee rivers. The absence of beds of conglomerate at the junction indicates deposition in still and deep waters.*

(4.) *The North-western Boundary Fault.*—On looking at Griffith's Geological Map it will be observed that the boundary line between the old gneiss and the quartzites and limestones stretches in a S.W. direction from a point W. of Glen to Dunlewy, a distance of 17 miles, in nearly a perfectly straight line. This line we found to be a fault of large vertical displacement (Fig. 5, Plate XXI.) The evidence at the two points where it was crossed by us is clear and decisive. One of these points occurs at the western entrance to Barnesbeg Gap—east of Creeslough.

The section taken through this village—and extending for at least two miles from the boundary-fault—lays open a great succession of beds consisting of schists, quartzites, and blue limestones, with beds of hornblendic diorite—dipping steadily towards the south-east at angles varying from 45°–70°. On approaching the boundary of the gneiss, indicated by the sudden rise of the ground into the rugged heights of Croagh, the beds approach the vertical position, and are terminated by a sharp reversed fold at the margin of the gneiss itself. Here the rock is shattered, full of veins and of "fault-rock."

This fault passes by Lackagh Bridge, the base of Croagh, through Loughs Agarrowen, and Aganive, and Calaber Bridge to Dunlewy—the exact position being determined at this last-named locality by the verticality of the beds laid open in the roadside north of the Church. Here, on the one side, we find the quartzites, schists, and diorite beds of Errigal; on the other—the beds of gneiss, schist, and crystalline marble of the Laurentian series. The direction of the boundary changes at Dunlewy Lough, and takes a westerly direction along the valley of the Claddy River. This line is also in all probability a fault-boundary, meeting the former at an obtuse angle near Dunlewy House.

The position of this fault is shown in a section taken across Central Donegal (Fig. 5, Plate XXI.), which also shows the relations of the Laurentian and Lower Silurian beds on the eastern flanks of the Laurentian Gneiss.

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* The nature of the relations between the Lower Silurian and Laurentian beds of the North of Ireland is somewhat similar to that between the Lower Carboniferous and upper part of the Old Red Sandstone with the Glengariff beds in the South. In both cases there is an unconformable overlap of the newer beds upon a shelving bank of the older.

PART II.

Probable Laurentian Districts of other parts of Ireland.

(1.) *Slieve Gamph and Ox Mountains.*—This is a narrow belt of hilly, almost mountainous, ground, extending from the north of Castlebar by Loughs Conn and Cullen to Manor Hamilton, and bounded by Carboniferous rocks on both sides. This range of hills forms a high and rugged background to the wooded slopes which border Lough Gill, near Sligo.

The rocks of this range consist of massive gray and reddish gneiss, often porphyritic, together with beds of hornblende and micaceous schists, sometimes quartzose. Interstratified with the gneissic beds are those of crystalline limestone, seen near Lough Talt and Lough Alone.* In Correagh Glen, south of Lough Gill, a remarkable bed of dark green massive serpentine occurs in this series, underlaid by quartzites and quartz-schist, and overlaid by gneiss with red felspar. The serpentine is about 350 feet in thickness, and contains numerous bands of chrysotile and magnetite.†

The massive gneiss bordering Lough Cullen, and extending southwards for several miles, is well foliated, porphyritic, and is of a red or flesh colour from the large quantity of orthoclase it contains, along with which is black and white mica and quartz. This rock passes beneath a great series of micaceous and hornblendic schists with granite veins, and contains crystals of rutile and tourmaline.‡ These old and highly metamorphosed rocks are bounded along the western edge by a large downthrow fault, ranging north and south in the meridian of Castlebar, and bringing into juxtaposition quartzites and schistose beds, not so highly metamorphosed as those east of the fault.§ It may be assumed provisionally that the rocks on the east side of the fault are of Laurentian age, and those on the west of Lower Silurian age, as they belong to the great series of schists and quartzites which range from Nephin westwards and northwards through North Mayo.||

(2.) *Belmullet, Co. Mayo.*—For some time past the officers of the Geological Survey have entertained a strong impression that the remarkable beds of gneiss which are found in the central and northern portion of the promontory of Belmullet are of Laurentian age.¶ The recent determination of the age of the Donegal beds which those of Belmullet closely resemble adds fresh probability to this view. The beds are thus described by Mr. A. M'Henry:—"The rock (gneiss) varies in colour from pale pink or red to gray and light brown, and is generally thick bedded, highly, sometimes coarsely, crystalline and felspathic. It contains distinct crystals of pink

* Expl. Mem. Sheet 65. By R. G. Symes and S. B. Wilkinson.

† Pointed out to me by Mr. Hardman.

‡ R. G. Symes. Expl. Mem. Geol. Survey. Sheet 75, p. 25–6. § *Ibid*, p. 24–5.

|| Sheets 64 and 75 of the Geological Survey Map. At the time these maps were being surveyed there was no evidence to show to what geological period the rocks here described were referable. Griffith evidently considered them of greater antiquity than the rocks of N. W. Mayo, as shown on his map.

¶ See Expl. Mem. Geol. Survey. Sheets 39, 40, 51, and 52, p. 13.

and whitish orthoclase felspar, also a pale grayish triclinic species (probably oligoclase) quartz, black, white, and bronze mica, and hornblende. In some instances beds of considerable thickness occur almost entirely composed of red or pink felspar, containing traces of the metal antimony (as determined by Mr. E. T. Hardman), while in others the beds are almost entirely composed of hornblende and mica."

These remarkable red gneissose beds are bounded on the east by a fault which brings the quartzites and schists of the Lower Silurian period against the Laurentian beds. On the west they form the shore of the Atlantic where they are laid open to view, much flexured and contorted.

(3.) *Galway District.*—To the north of Galway Bay, and extending inland for some distance, is a wild tract of country—indented by numerous arms of the sea—full of lochlets—rocky, and (except where bosses or ridges of rock rise above the general surface) deeply overlaid by morass and peat. It strongly resembles some tracts in Sutherlandshire formed of Laurentian gneiss or schist, such as that stretching from the base of Ben Foinaven and Ben Arkle to the coast, or the tract about Kylesku and the shores of Loch Dow. In both districts the rocks are glaciated and boulder-strewn, and in both they consist of similar materials; and, as I now feel confident in affirming, they are of similar geological age.

The rocks composing the Galway tract have been fully described by Mr. Kinahan.* They consist of beds of gneiss, composed of "pinkish" or flesh-coloured felspar (orthoclase), more or less porphyritically developed; greenish, or yellowish waxy felspar (oligoclase), quartz; black, green or white mica, with other minerals.† These beds pass into others in which hornblende and mica predominate, and are traversed by veins "of a coarsely crystalline variety of granite that answers the description for Cotta's 'pegmatite.'" Along with foliated and porphyritic red gneiss occurs an "intrusive orthoclase or highly silicious (gray) granite" of later date.

The tract occupied by this old Galway gneiss is bounded along the north by the quartzite mountains, known as "The Twelve Bins of Connemara," formed of beds which, together with the overlying schists and limestones, represent the metamorphosed Lower Silurian beds of Donegal and the North Highlands of Scotland.‡ At the point crossed by the section of the Geological Survey (Sheet 25) the boundary between the two sets of rocks is a fault; to the south of which, and extending to Kilkieran Bay, there occurs a great thickness of schistose beds, chiefly hornblendic, with others of red gneiss and hornblende rock, and having at the base of the whole the porphyritic granite or gneiss of Avoch, consisting of large crystals of pink orthoclase felspar, greenish oligoclase, quartz, and black and white mica, and forming

* Expl. Memoirs of the Geological Survey. Sheets 93, 94, 105, and 114.

† This is Mr. Kinahan's "Galway type granite."

‡ This is the view expressed by the Director-General of the Survey, Professor Ramsay, as far as regards the comparison with the Scottish area, after a visit paid to the district in 1877. See Preface to Expl. Mem., Sheets 93, 94, &c. The relative position of the Laurentian and Lower Silurian beds, is represented in the Horizontal Sections, published by the Survey, Sheet 25.

the shore of Kilkieran Bay. The section shows a thickness of these beds of about 18,000 feet, and is illustrated in Figure 6, Plate XXI.

The resemblance of these beds, both to those of Laurentian age in Donegal and in the Northern Highlands, is almost complete; and with the experience and knowledge gained since the Survey was finished in Galway, I can have no hesitation in referring them to the same period of geological time.

Absence of Cambrian Beds in the North and West of Ireland.—Nowhere throughout Donegal, Mayo, Sligo, or Galway have we any evidence of the existence of Cambrian beds between the Lower Silurian and the Laurentian series. Considering the relations of these districts to those of the West and North Highlands, it may be supposed that Cambrian beds, had they been present, would have assumed the character of the rocks of this formation as they occur in the North-west Highlands of Scotland; that is, the form of reddish sandstones and conglomerates, unconformable alike to the Laurentian beds below and the Lower Silurian beds above. But we fail to recognise any rocks having these characters and relations throughout the region referred to, in consequence of which there is here a double *hiatus* as compared with Scotland, except in those districts in Sutherlandshire, where the Lower Silurian beds rest directly upon the Laurentian. To this subject I shall have occasion to return presently (Page 256).

(4.) *Tyrone Rocks.*—I have now to refer to a district in which the relations of the beds are somewhat obscure, but which is mineralogically of great interest. It has recently been referred to by Dr. Hicks as being probably one of his numerous "Pre-Cambrian" areas.* It lies in county Tyrone, in the vicinity of Pomeroy; and as the Geological Survey is still being carried on over the area, immediately to the north, and as the question regarding the relations of the rocks is still to a certain extent *sub judice*, I shall only briefly describe the locality here, in order to show exactly the conditions of the problem.

The district in question forms a range of hills, having a general trend from west to east, of which Craigballyharky (771 feet) Caragrim (710 feet), Cregganconree (993 feet) and the Scalp (859 feet) are the most elevated prominences.†

This range consists of granitic, pyroxenic, and felspathic rocks in great variety—chiefly of metamorphic origin, described by General Portlock,‡ and more recently, and in great detail, by Mr. Nolan of the Geological Survey.§ Mr. Kinahan considers them of "Cambrian" age or "an older formation."‖ Along the south these old rocks are bounded by conglomerates of "Lower Old Red Sandstone" age, but now generally recognised as representatives of the "Dingle Beds," lying at the

* Proc., Geologists' Association, Vol. VII., No. 1, p. 28.

† Expl. Mem., Sheet 34 of the Geol. Survey, by Joseph Nolan (1878).

‡ Geol. of Londonderry, &c., the term pyroxenic in here used to include rocks in which both hornblende hypersthene, augite, and diallage are prevalent, and appear to be associated with each other.

§ Geol. Mag., April, 1879. The reader will find ample details in Mr. Nolan's paper.

‖ Proc., Royal Irish Acad., Dec., 1880.

margin of the Silurian and Devonian series, and for which I have suggested the term "Devono-Silurian." But in the neighbourhood of Pomeroy there occurs a series of greenish slates and flags in which Portlock discovered a remarkable series of Lower Silurian fossils, which have made them well known amongst geologists as "the Pomeroy Beds." The fossils from this series, having received accession from the examination of the officers of the Survey, have recently been revised and tabulated by Mr. Baily, F.G.S., Acting Palæontologist to the Irish Survey, and are given at length in the Explanatory Memoir to accompany Sheet 34 of the Geological Map. The list is exceedingly copious, and, in Mr. Baily's opinion, indicates that the beds are referable to the "Caradoc" or "Bala" stage of the Silurian series.*

The relations of these beds to the metamorphic rocks lying to the north and west of their position is unfortunately very obscure; and on the Survey map the two formations are separated by faults, by which the "Bala beds" are brought down against the metamorphic rocks. We are, therefore, driven to other kinds of evidence than that of superposition of strata, in order to determine, as far as possible, the geological age of the metamorphic series. The question is whether these rocks belong to the Laurentian ("Pre-Cambrian") or to the metamorphosed Lower Silurian series. In Griffith's map they are represented under the same colouring and lettering (Ye.) as the rocks of the Ox mountains in county Sligo, which I have already referred to the Laurentian series. Sir R. Griffith was, evidently, of opinion that they are of older age than, and that they underlie, the great metamorphic series, which occupies the greater portion of the county of Londonderry, from Lough Foyle and Lough Swilly southwards;—beds forming the upper portion of the Lower Silurian metamorphic series. In this case the lower beds which rest on the Laurentian series of Donegal might possibly be represented by the Tyrone rocks. There is, however, so little resemblance in the characters of the two sets of rocks that this view appears highly improbable. So far the evidence is in favour of their Laurentian age.

On the other hand, as the fossiliferous beds of Pomeroy belong to the Bala series, it may be supposed that they overlie several thousand feet of representatives of the "Llandeilo" and, possibly, "Arenig" beds; and these, being deeper seated, might have been metamorphosed, while the overlying shallower beds might have remained (as at Pomeroy) unaltered; these lower beds would be concealed along the lines of fault above described, and only appear on the upthrow side where they are exposed by denudation.

I have thus endeavoured to put fairly the uncertainties attending the determination of the geological age of the Tyrone rocks; and, on considering the whole question, I am inclined to concur in Dr. Hicks' view of their Pre-Cambrian age, partly on stratigraphical, but chiefly on petrological, grounds. They may probably be viewed as an "Upper Laurentian" series not represented in Donegal. Additional

* Dr. Hicks (quoting from Mr. Kinahan) calls these beds "Cambro-Silurian," a term which seems to have somewhat misled Dr. Hicks in his speculations regarding the age of the crystalline rocks. A reference to Survey Documents or to Portlock's work would have shown him the exact age of the beds.

evidence towards the solution of the question will probably be obtained upon the completion of the survey over the eastern and southern parts of Londonderry now in progress.*

It has been suggested that these rocks are of "Cambrian age." In this view I cannot concur, on the ground that if they were of this age they ought to bear some resemblance to the Cambrian beds of the West Highlands of Scotland. To these they have not the remotest resemblance; and, on a general review of the evidence, I feel disposed to refer them to an "Upper Laurentian" stage not rising to the surface in Donegal owing to the overlap of the Lower Silurian beds, but emerging from under these beds along their southern border.—(See Map on Plate XXI.)

Reasons for the absence of Cambrian Beds in the North and West of Ireland.

In another place I have endeavoured to account for the absence in the north and west of Ireland of those great beds of red sandstone and conglomerate which are interposed between the Lower Silurian quartzites and limestones of the North Highlands of Scotland, and the Laurentian gneiss of the same region, and which form so conspicuous a physical feature in West Highland scenery. According to the views referred to, I have supposed that during the Cambrian period there existed an old Archæan ridge lying in a north-east and south-west direction over the region now occupied by the Grampian Mountains on the north and the Donegal, Sligo, Mayo and Galway Highlands on the south. This ridge, having been unsubmerged, formed a tract of land of crystalline rocks—on either side of which the Cambrian beds were deposited—those on the north-west side, in the waters of an old lake (as suggested by Professor Ramsay), those on the opposite side (including the Cambrian beds of the east of Ireland of Wales and Shropshire, &c.), in the waters of the sea.† Owing, therefore, according to this view, to the Donegal district, as well as those of Mayo, Sligo and Galway being in a condition of dry land during the Cambrian period no strata were deposited over these areas, which were, on the other hand, exposed to a process of denudation during the Cambrian period.

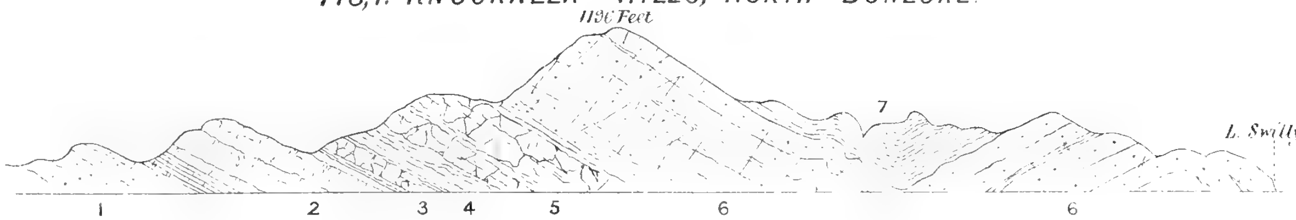
* Mr. Nolan in a letter, dated 8th June, says, "I have nothing to say against the view that the highly metamorphic rocks of Tyrone may be of Laurentian age. They graduate into gneiss their area, but their relations to the great mass of schists on the north is (as you say) obscure."

† For the reasons on which these views are based the reader may refer to my paper "On the two types of Cambrian beds of the British Islands (the Caledonian and Hiberno-Cambrian), and the conditions under which they were respectively deposited," Proc. Brit. Assoc. (1881.) Trans of Section C.; also Quart. Journ. Geol. Soc. Lond., No. 412, 1882.

EXPLANATION OF FIG. I.

7. *Various Schists.*
6. *Quartzite, and Quartz Schist.*
5. *Beds of Hornblende Rock or Diorite.*
4. *Schists.*
3. *Hornblende Rock.*
2. *Limestone.*
1. *Quartzite &c.*

FIG. I. KNOCKALLA HILLS, NORTH DONEGAL.



LOWER SILURIAN BEDS.

FIG. 2. SECTION IN THE GLEN RIVER
Shewing Lower Silurian Schists (S) resting against an old Shelving Surface of Laurentian Granitoid Gneiss (A)

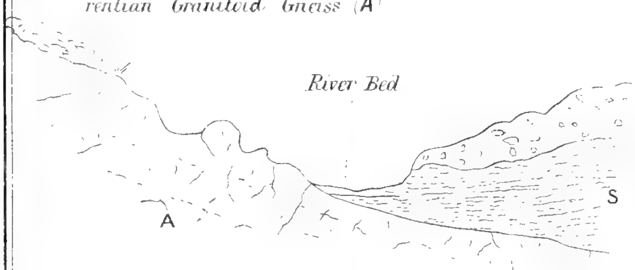


FIG. 3. SECTION AT LAKE SALT.
To show relations of Lower Silurian to Laurentian beds.

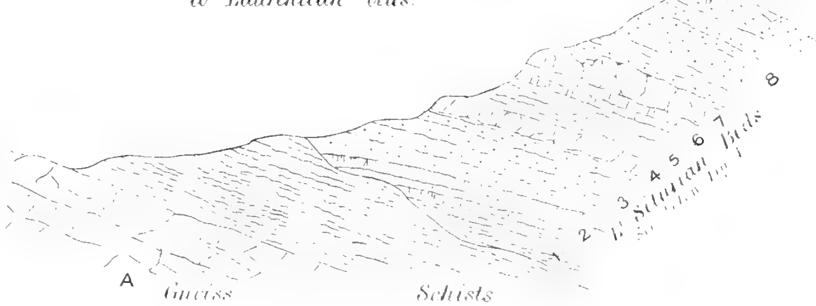
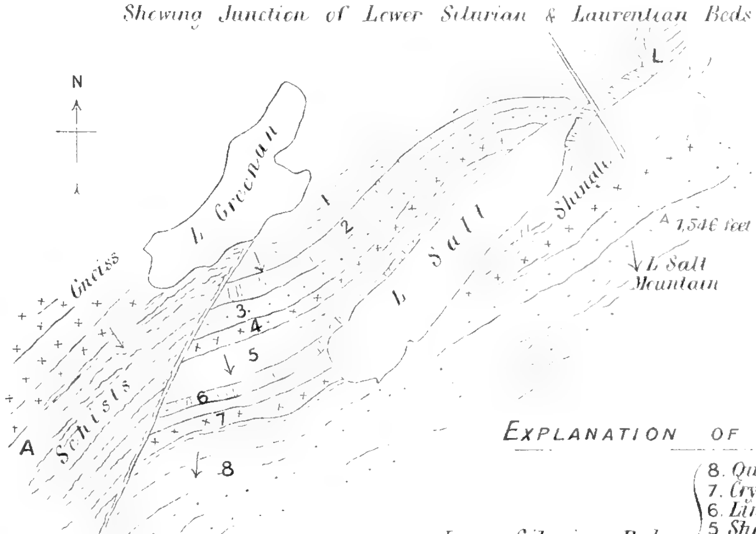


FIG. 4. PLAN OF L. SALT
Shewing Junction of Lower Silurian & Laurentian Beds



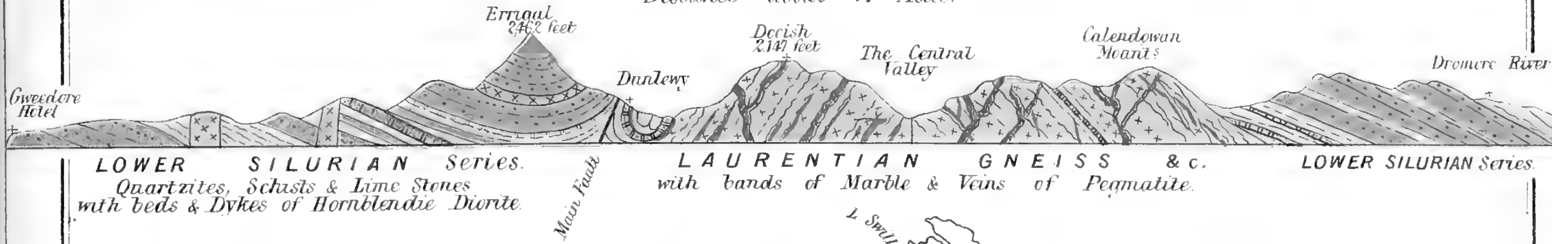
EXPLANATION OF FIGS. 3 & 4.

Lower Silurian Beds:
8. *Quartzite.*
7. *Crystalline Diorite.*
6. *Limestone 30 40 Feet.*
5. *Shales.*
4. *Hornblende rock.*
3. *Quartzite.*
2. *Limestone 100 Feet.*
1. *Schists &c.*

A. *Laurentian Gneiss, and Schist.*

Forster & Co. Lith. Dublin.

FIG. 5. SECTION ACROSS CENTRAL DONEGAL FROM WEST TO EAST.
Distance about 17 Miles.



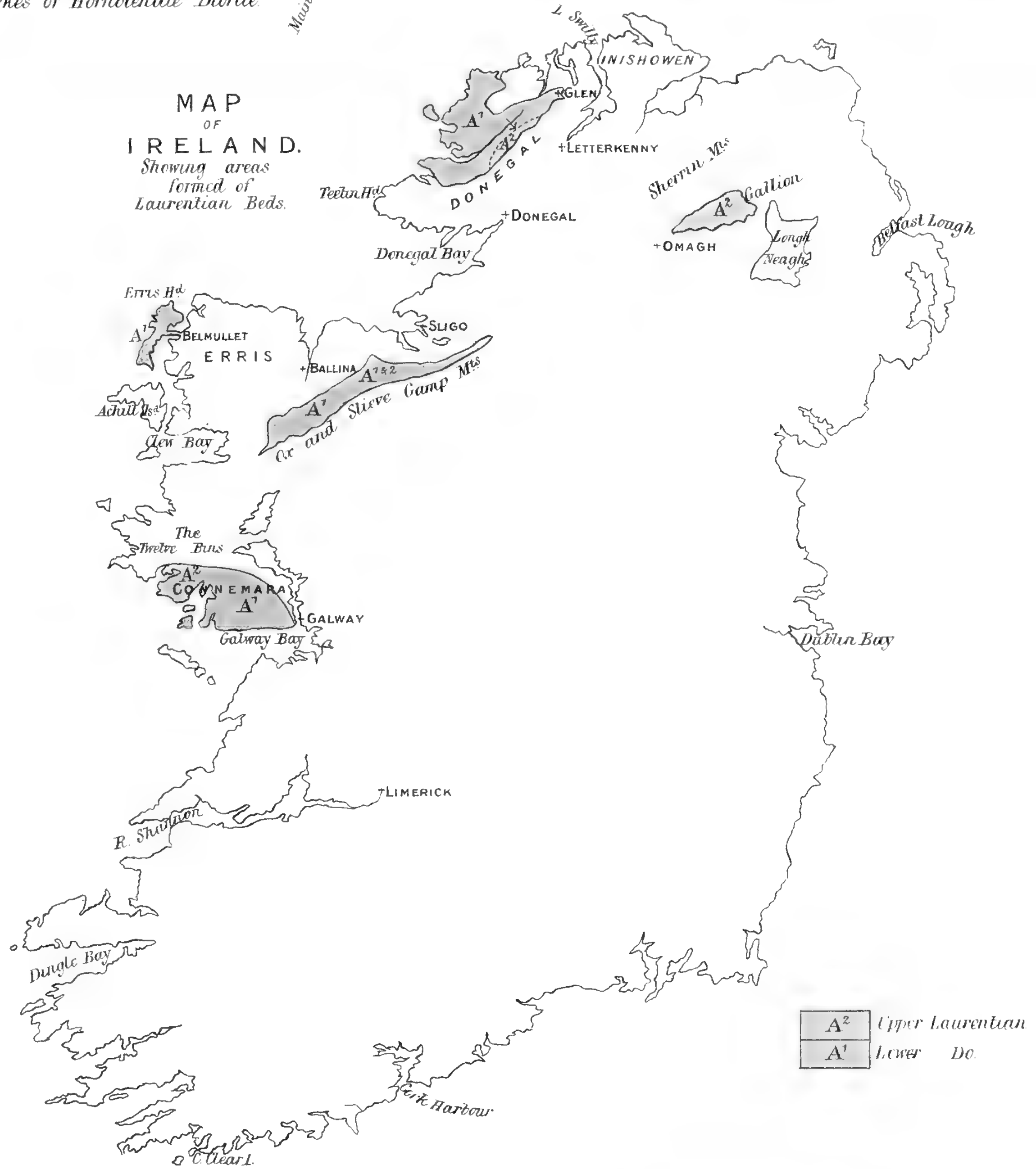
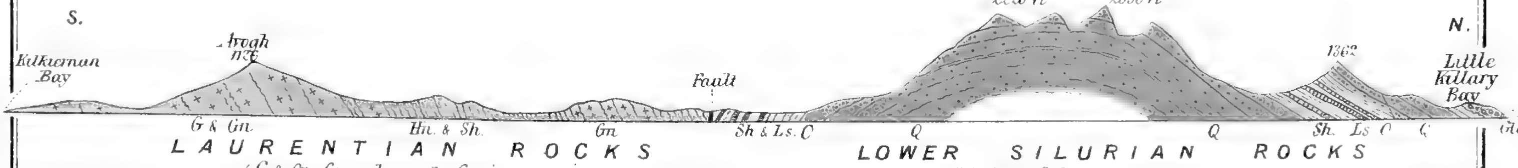


FIG. 6. HORIZONTAL SECTION ACROSS CONNEMARA, C^o GALWAY.
Showing position of Laurentian and Lower Silurian Metamorphic Rocks



Laurentian Rocks. { G & Gn Granite and Gneiss; Hn Horblende Rock or Schist; Sh. Various Schists.

Lr. Silurian Rocks { Sh. Various Schists; L. Limestone; O. Ophi-calcite; Q Quartzite, Quartz-Schist.

Gte. { Upper Silurian Conglomerate

Forster & C^o Lith, Dublin.

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[NOVEMBER, 1882.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

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XIX.—*Palæo-Geological and Geographical Maps of the British Islands and the adjoining parts of the Continent of Europe.* BY EDWARD HULL, LL.D., F.R.S., &c., *Director of the Geological Survey of Ireland, and Professor of Geology in the Royal College of Science, Dublin.*—PLATES XXII. TO XXXV.

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By Edward Hull, ll.d., f.r.s., &c., Director of the Geological Survey of Ireland, and Professor of Geology in the Royal College of Science, Dublin. Plates XXII. to XXXV.

Introduction.

The preparation of a series of maps showing the relations of land and sea during successive geological periods over the British area has been an undertaking which I have long contemplated, but, until now, did not see my way to carry out. The idea has, doubtless, suggested itself to other geologists; and I cannot but feel surprise that, except very partially, no one has hitherto made the attempt to realize it. I understand from the Rev. Dr. Haughton, of Trinity College, Dublin, that about a quarter of a century ago, the late Mr. William Longman, the then head of the eminent publishing firm, expressed a wish to have such a set of maps prepared for publication, and suggested that he (Dr. Haughton) should undertake their preparation. Circumstances prevented this; but it may be affirmed with some confidence that the time had not then arrived when this task could have been accomplished with satisfactory results; because it is within this period that much of our present knowledge of the structure of, at least, the English area has been obtained by the details collected and portrayed on maps by the Government Surveyors, and by the numerous deep underground boring-experiments which have been made at intervals over a large portion of the centre or south of that country in search of either coal, water, or for other purposes. These borings have been of the greatest interest to geologists, though perhaps not always equally so to their projectors, because they have revealed the internal structure of a large extent of country which would otherwise have been the subject only of conjecture or of geological inference. For the present purpose they have proved of material use. Certainly, without their aid it would have been impossible for me to have shown accurately, the range of the Triassic, Liassic, and Oolitic formations in the direction of the Thames valley and of the eastern coast, after they had been successively lost sight of beneath the more recent deposits.

These borings have also thrown much light upon the position of the Carboniferous, Devonian, and Silurian rocks below the Cretaceous area; and though they have not solved the question so ably handled on physical grounds by Murchison, Godwin-Austen, and Prestwich—" Where may coal be found under the newer formations of the South of England," they have to a very large extent shown where the

coal-formation does *not* exist, and what kinds of strata occupy its place. Now, nearly all the borings which have thrown any light on the internal structure of sub-Jurassic or sub-Cretaceous areas have been made within the last quarter of a century; and until they had been made, geologists were not in a position to deal with any degree of certainty with the problems I have referred to, much less to represent their views on physiographical maps.

In tracing out the range of special formations over tracts of country of considerable extent and noting the changes they undergo, the mind is naturally led to speculate on their original extent and distribution before they had undergone the denudation or waste, to which they have subsequently been exposed. The formations of the British Isles and of the adjoining parts of the European continent are only fragments of the original masses; they have been disturbed from their once horizontal position, tilted into various angular inclinations from the horizon, and have undergone much waste, so that we seldom meet with the original "shore beds" which were deposited in the waters of the sea or lake (as the case may be), along the margins of their hydrographical areas. Hence we are led on to speculate regarding the position of the old lands which yielded the sediment of which the strata are formed, or which bounded their areas of deposition. In order to arrive at conclusions on these subjects, we have to note the directions in which these special formations expand in thickness, and those towards which they appear to thin away. Generally speaking, and within certain limits, formations composed of sedimentary materials, such as gravel, sand, clay or mud, tend to increase in thickness in the direction of the land from which these materials were carried down and spread over the area of deposition. On the other hand, formations of this kind rapidly thin away in the direction of any tract of contemporaneous land, against the shelving bed or shore of which they were deposited, but which may not itself have contributed much, if any, sediment during their deposition. The old ridge of Lower Palæozoic rocks which stretched across the centre of England during the Carboniferous and Permian periods was of this kind.* Itself of too limited an extent to be a source of sediment, the newer formations simply tail out towards its margin both to the north and to the south. The sub-Cretaceous ridge of a subsequent period was of a similar kind.† While it formed a land-surface against which the Triassic and Jurassic formations successively wedged out, it was not itself a source of sediment, and these formations terminate along its border, but little changed in their mineral characters on approaching its position. On the other hand, limestones formed over the bed of the sea by organic agency, become split up by bands of sandstone or shale in the direction of the lands of the period from which sandy or muddy sediment was being carried down by streams; but on approaching barriers of land, or isolated tracts of older rock of limited extent, they wedge out towards

* Plate XXVIII., Fig. 2.

† Plate XXXI., Figs. 1 & 2.

the margin without much change in their characters; of these two phenomena the Carboniferous and Jurassic limestones offer striking examples.*

In determining the position of the land surfaces, and submerged areas during successive geological periods, one of the most important guides is the discordant, or unconformable, relations of the strata to those of older date. Where two sets of strata, such as those of the Triassic and Silurian periods, are highly discordant to one another, there is much probability that the older formation was in some region in the position of a land surface when the newer formation was being deposited under the waters of an adjoining sea or lake. In this case the actual margin is frequently indicated by the abrupt uprising of the older formation with reference to the newer, allowance being in all cases made for the effects of denudation. If the two unconformable sets of strata immediately succeed each other, or are in close geological sequence, then the marginal relations are more easy of determination. Such is the case, for instance, with the Lower and Upper Silurian strata, which, though highly discordant as regards stratification, are in immediate geological sequence, and the original marginal beds, those of the upper Llandovery age, are found in the form of conglomerates not far removed from their position as shore beds.† Throughout the whole succession of formations from the Cambrian to the Cretaceous there is no more marked physical break than that which occurs between the Lower and Upper Silurian formations over the area of the British Islands.

The occurrence of beds of conglomerate, or breccia, is generally an indication of littoral conditions, and indicates the proximity of the land of the period to which they belong. Thus, the breccias which occur in the New Red Sandstone in two stratigraphical positions in Shropshire and Worcestershire, and which thin away eastward, indicate the proximity of the marginal land formed of Devonian, Silurian, and Cambrian rocks, in the adjoining districts west of the Severn. The conglomerates of the Old Red Sandstone along the southern slopes of the Grampians, and in other places, point to similar conditions; but it is remarkable to how great a distance rounded pebbles have been transported in some instances from their original sources; as, for example, in the case of the New Red Conglomerate of the central counties of England, the source of supply for which was apparently in Scotland.‡

When engaged in the attempt to restore the physical features of successive geological periods over the region embraced in this treatise, I became forcibly impressed with two leading ideas. First, that the present North Atlantic Ocean,

* Some years ago I illustrated these phenomena in a paper on "Isodiametric lines, and the relative distribution of the calcareous and sedimentary beds of the Carboniferous system."—Quart. Jour. Geol. Soc., vol. xviii., p. 127.

† This can be observed both in Wales and the West of Ireland.

‡ On the origin of the quartzite pebbles of the Bunter Conglomerate, see "The Triassic and Permian Rocks of the Midland Counties of England," p. 59.—Mem. Geol. Survey (1869).

must for a long lapse of time have been a continental area, whence was derived to a large extent the sediment of which many of our formations are composed; and, secondly, that the Old Highland districts of the British Isles, once they had sprang into existence as such, ever after endeavoured to retain their ascendency.* This is the case with the mountains of North Wales, those of the Scottish Highlands, and of Donegal, Galway, and Wicklow, in Ireland, which all rose into mountain forms or elevated positions during that long interval of time which elapsed between the close of the Lower, and the commencement of the Upper Silurian epochs.† Notwithstanding the enormous amount of waste to which these old mountain groups have been subjected, it is doubtful if at any time subsequently they were completely buried beneath more recent strata. In several instances, however, this was nearly being the case; as, for example, during the epochs of deep depression in the Upper Carboniferous and Cretaceous periods.‡

The first idea above referred to is one of great interest, and seems to run counter to the prevalent theory, that the existing oceans have been such from very remote geological periods. If this were the case, the existing Continents must equally have been Continents throughout an equal distance of time; but, if so, how could they have been covered so largely by marine strata, belonging to Silurian, Devonian, Carboniferous, Jurassic, Cretaceous, and Eocene Tertiary times?

The conclusion has been forced on my own mind, that the North Atlantic was mainly land during the Laurentian, Cambrian, and Lower Silurian periods, and was the source of the sediment of which these great formations are composed. It probably first assumed large proportions as a sea or ocean, when so much of the *then sea* became land, namely, at the close of the Lower Silurian period; but there are grounds for believing that it was largely in the condition of a land surface in still later times, namely, during the Carboniferous, Permian, Triassic, and Jurassic periods, as evinced by the thickening of the sediment both towards the north-west and south-west of the British Isles.§ This great continent of *Atlantis* was the parent of much of the strata which now overspreads the plains of Britain and of the adjoining continental areas. With the Cretaceous period its permanently oceanic form and features set in, and were vastly extended during that and the succeeding period of the nummulitic limestone.

* Prof. Sir A. Ramsay has shown that the mountains of North Wales became such before the Upper Silurian period, and it is doubtful if they were ever subsequently completely buried under strata of any newer formation.—See "Phys. Geol. and Geog. of Gt. Britain," 4th edit.

† "Phys. Geol. and Geog. of Ireland," p. 123 *et seq.* (1879.)

‡ See Maps, Plates XXVIII. and XXXII.

§ I have shown this to have been the case with reference to the Carboniferous Rocks.—Quart. Journ., Geol. Soc., vol. xviii., p. 142, and of the Lower Secondary Rocks, *Ibid.*, vol. xvi., p. 63 *et seq.*

Plate XXII.

The Laurentian Period.

This plate (Fig. 1), is intended to show those tracts where the Laurentian rocks reach the surface, and those under which they may be supposed to extend, though concealed beneath more recent formations ; also, the portions of the surface over the western part of the European area, including the British Isles, occupied by the land and sea of the Laurentian, or Archæan, period (Fig. 2).

The Laurentian Continent (*Atlantis*).—As the Laurentian rocks form extensive tracts both in North America and Europe, it may be inferred that the land which was the source of the sediment of which they are composed was situated in a region lying between these two areas; that is to say, in the region of the Atlantic Ocean, including probably the continent of Greenland, and possibly the Polar regions. It may be supposed that large rivers flowed down into the ocean of the period, both towards the west and towards the east, and that this sediment was deposited over the floor of the Laurentian ocean, now occupied by North America and Europe. The margins of this land are necessarily only approximately inferential.

Laurentian Areas (Fig. 1).—The Laurentian (or pre-Cambrian) rocks appear at the surface (over the area embraced by the map), as forming the greater portion of the Scandinavian promontory, in the north-western Highlands of Scotland, and outer Hebrides, in the north-west of Ireland and Galway, in the centre and north-west of France, and along the margin of the Silurian basin of Bohemia. They may be supposed to underlie all the remaining portions of the land, except those districts formed of intrusive granitic or trappean rocks, which, as compared with the former areas, are very small, and can only occasionally be represented on a map of the scale here adopted.

Nature of the Laurentian Rocks.—These rocks consist of foliated granite or gneiss, hornblendic and micaceous schists, crystalline limestone or marble. The gneiss is generally massive, porphyritic, and of a red colour, consisting of orthoclase, oligoclase, quartz, and mica of two varieties. To this formation, the red granite of the Nile valley probably belongs.

The Laurentian rocks have undergone intense metamorphism, owing to which they now only occur in a crystalline condition. Originally, there is every reason to believe, they were formed of sedimentary materials, such as those of the Lower Silurian system, consisting of sandstones or grits, slates, flagstones, and limestones, all of marine origin; and whether or not the *Eozoon Canadense*, found in this formation in Canada, be a true organism, the occurrence of beds of limestone leads us to infer that the ocean-waters of this early period of geological history were not destitute of living creatures, though probably of very simple organization.

Plate XXIII.

The Cambrian Period.

The physical conditions of the Cambrian period over the British area contrast strongly with those of the Laurentian. Previous to the deposition of the Cambrian beds,* those of the preceding Laurentian period had been metamorphosed, elevated into land-areas, and largely denuded, so that the bed of the Laurentian ocean (Plate XXII.) now appears as part of a large continental area, embracing the northern and western portions of the British Isles; while the ocean extended over the western districts of Europe, the whole of England, and parts of Scotland and Ireland.

Submerged Cambrian areas.—From considerations stated at length elsewhere,† I have arrived at the conclusion, that during the Cambrian period, an archæan ridge formed of Laurentian strata stretched through the British Isles in a S.W. and N.E. direction, embracing the region of the west of Ireland, and of the Grampian Mountains, by which the Cambrian beds of the N.W. Highlands of Scotland were separated off from their representatives of the English and Welsh areas. This conclusion depends in part on the extreme dissimilarity existing between the representative beds on either side of the supposed ridge. I shall, therefore, describe the beds under the two types which I have called, on the occasion referred to, those of the "Caledonian," and "Hiberno-Cambrian."

Cambrian Beds of the Caledonian type.—These are restricted to the north-western Highlands of Scotland, where they occur interposed between the Laurentian rocks below, and the quartzites, limestones, and shales of the Lower Silurian beds above. They consist of great beds of red and purple sandstone and conglomerate, generally in nearly horizontal positions, forming bold escarpments, and isolated pyramidal masses. The pebbles of which they are mainly formed consist of various kinds of gneiss, schist, porphyry, and quartzite;—presumably derived from the adjoining land-areas of Laurentian strata. Professor Ramsay considers these beds to have been deposited in the waters of an inland lake, of which the outer Hebrides formed the western margin.‡ In this view I concur. No fossils have been found in these lacustrine beds.

Cambran Beds of the Hiberno-Cambrian type.—These are vastly more extensive than the former; and, though they only crop out to the surface in a few places, may be presumed to underlie nearly the whole of England and Wales, as well as the adjoining parts of Europe. They consist of green and purple massive grits, quartz rocks and slates, with, occasionally, pebbly beds; and as the fauna is distinctly marine the

* I use the term Cambrian to include the Longmynd, Harlech, and Llanberis beds, together with the overlying Upper Cambrian Lingula flags, as the fauna of the latter has been shown by Dr. Hicks to be present in the former. I therefore take the base of the Silurian series at the Tremadoc slates.

† "Quart. Journ., Geol. Soc.," May, 1882, p. 210, and Brit. Assoc. Rep. (1881, p. 642.)

‡ "Phys. Geology and Geography of Great Britain," 5 edit., 283, &c.

beds may be inferred to be of oceanic origin. Cambrian rocks of this type are found in the east of Ireland, with *Oldhamia*, a sertularian zoophyte, and annelid tracks and borings, such as those of *Histioderma*. In North Wales and Shropshire they have yielded trilobites,* while the Upper Cambrian beds are rich in marine forms. At St. David's, Dr. Hicks has brought to light several genera of trilobites in beds contemporaneous with those of the Longmynd and Harlech group of North Wales. These rocks also are found in Charnwood Forest, in Leicestershire,† where they are in some places altered or metamorphosed, and associated with trap rocks; in the Ardennes mountains, on the borders of France and Belgium, where they consist of quartzites, quartz-schists, and schists, with *Oldhamia radiata* (one of the Irish species), *Dictyonema sociale, Lingula,* and tubes or impressions of annelids.‡ In the Système Salmien, forming the upper division of the series, trilobites of the genus *Paradoxides* have been discovered by M. Malaise.§

These rocks also occur in Normandy and Brittany, consisting of green slates and grits, resting on gneiss and schist, which is probably of Laurentian age.

Regarded as a whole, the Cambrian beds of the region now described are clearly of marine origin, and present—both in lithological characters, and from the occurrence of a marine fauna—a marked dissimilarity to the beds of the Caledonian type.

Plate XXIV.

The Lower Silurian Period.

With the commencement of the Lower Silurian period,|| the ocean resumed the dominion it had partially lost during the preceding Cambrian period; and as time went on, the entire area of the British Islands and adjoining parts of Europe became submerged and covered with sediment. It may be confidently affirmed, that there is not a square mile over this region which was not originally buried beneath strata belonging to the Lower Silurian period. The old archæan ridge was covered by strata still in existence; and even the Cambrian and Laurentian rocks of the north Highlands of Scotland were, in the opinion of Sir A. C. Ramsay, submerged and buried under the accumulating piles of these strata before that era passed away.¶ Land was, however, probably not far away, and its position was to the north-west of the British Isles.

* Discovered by Mr. Salter in the Longmynd beds.

† I regret I cannot agree with Dr. Hicks and several other distinguished geologists in regarding these beds otherwise than of Cambrian age, to which they were originally referred by Professor Jukes.

‡ Dr. Mourlon, "Géologie de la Belgique," t. 1., p. 31.

§ Dalimier, Bull. Soc. Géol. France, 2 Ser., vol. xx.

|| I assume the base of the Lower Silurian series to be the Tremadoc slate or (in their absence) the Arenig beds, forming the lower part of the Llandeilo group.

¶ "Phys. Geog. and Geol. of Great Britain," 5 edit., p. 87.

Nature of the Lower Silurian Beds.—The strata of this period consist of dark and gray slates, grits sometimes calcareous, and, rarely, bands of limestone. The fossils are all of marine genera. Over the northern and western areas of the British Isles these strata have undergone extensive metamorphism, so that in the Highlands of Scotland, and of the north and west of Ireland, they consist of quartzites, micaceous, talcose, and chloritic schists, and crystalline limestones, sometimes serpentinous, with their varieties; presenting a marked contrast to their unaltered representatives in the south of Scotland, in Wales, and in the east of Ireland.

Relations to adjoining Formations.—The Lower Silurian rocks are discordantly superimposed upon all formations older than themselves. This is the case in North Wales, in the east of Ireland, and in the north of Scotland Owing to this discordancy, and the large amount of denudation to which the upper and lower Cambrian beds were subjected at the close of the Cambrian period, we find the Lower Silurian beds resting on strata of various stratigraphical positions. Thus in North Wales and Salop, the Arenig beds are found resting sometimes (as near Bangor and Carnarvon) on the purple slates and conglomerates of the Cambrian series;* sometimes, as in Pembrokeshire and Merionethshire, on the Tremadoc slates. In the east of Ireland in county Wicklow, the Lower Silurian beds rest discordantly on the Lower Cambrian beds; and in the north of Scotland, the quartzites and limestones representing the Llandeilo beds, rest discordantly sometimes on the Lower Cambrian beds, at others, on the Laurentian.

Lower Silurian Areas.—The principal districts where the Lower Silurian rocks form the surface, are the north and central Highlands and the southern uplands of Scotland, the Lake District of the north of England, the north and centre of Wales, the north-west, north-east, and south-east of Ireland, and the Isle of Man. They also occupy portions of Normandy and Brittany,† where they rest on Cambrian and Laurentian beds, and they have been proved by boring below the Tertiary and Cretaceous strata at Bruxelles (Brussels), Louvain, St. Tron, Menin, and Ostende in Belgium. They also appear at the bottoms of the valleys between the Sambre and the Meuse, as determined by M. Gosselet;‡ they probably underlie a large portion of the Paris basin, where they are concealed by Tertiary and Cretaceous formations.

Beds of marine origin.—The fossils yielded by the Lower Silurian rocks, whether in the north-west of France, in Belgium, in Wales, in Ireland, or in the north of Scotland,§ all go to prove the marine origin of the strata themselves. They consist chiefly of trilobites, molluscs—cephalopods, gasteropods (lamellibranchs not plentiful), and brachiopods—a few corals, and graptolites. The abundance of these forms in the calcareous beds prove that the waters of the sea teemed with living

* Ramsay, *supra cit.*, p. 78.

† Murchison "Siluria," 4th edit., p. 408.

‡ Quoted by Dr. Mourlon, "Géol. de la Belgique," p. 40. § From the Durness, or Assynt, limestone.

forms. In the Bohemian basin, as M. Barrande* has shown, there was a prodigious development of life; but often, though many hundreds of feet of slates and grits in some districts, no trace of organic structure is discoverable.

Plate XXV.

Upper Silurian and Devono-Silurian Periods.

The relative areas of land and sea during these periods differ widely from those of the period which preceded it, as will be seen on a comparison of Plates XXIV. and XXV. The sea which overspread the whole of the British Isles and adjoining portions of France and Belgium is now restricted mainly to the southern and central portions of the British Isles; while large tracts in the north and west, as well as Normandy and Brittany, are converted into land surfaces, holding in their deep depressions, lakes or fresh-water basins, which were formed towards the close of the Silurian period, or in more definite terms, during the Devono-Silurian stage.

Nature of the Upper Silurian Beds.—The basement beds of the Upper Silurian series (Llandovery beds) are frequently conglomerates and sandstones, derived from the disintegration of the rocks of the adjoining lands, and by their position we are able to indicate the position of the margins of these lands themselves. Such is the case in the districts of Connemara in the county Galway,† and of Builth in Radnorshire.‡ The succeeding beds consist of grits, shales and limestones of the Wenlock and Ludlow series, often rich in marine fossils. These beds occur in West Galway and Mayo, in North and South Wales, and Monmouthshire, in Staffordshire, along the southern slopes of the Cumberland mountains, and those of the southern uplands of Scotland. In the north of France and Belgium they are altogether wanting, as the Devonian beds rest against the shelving flanks of ancient lands formed of Lower Silurian and Cambrian strata.§

Devono-Silurian Beds.—Under this term I include a series of beds known by various names, and chiefly developed to the north and to the south of the British area. They include the "Passage beds" of Murchison, and the "Downton sandstone," lying at the top of the Upper Ludlow rock, in South Wales; the "Dingle and Glengariff Beds" of Jukes, forming the south-western mountains of Ireland, and seen resting conformably on the Upper Silurian beds along the coast of Dingle; "the Fintona beds" of the north of Ireland, which rest unconformably on older crystalline strata; and the "Lower Old Red Sandstone" of Scotland. The Devono-Silurian beds form the connecting series between the Upper Silurian and the estuarine Devonian beds of Monmouth and South Wales, and are probably re-

* "Syst. Sil. de la Bohème."

† "Phys. Geol. of Ireland," p. 23.

‡ Ramsay, "Phys. Geol. of England and Wales," p. 89.

§ Mourlon, "Géol. de la Belgique," t. 1, p. 54.

presented south of the Bristol Channel, by the "Foreland grits and slates" of North Devon.*

These beds were formed by accumulations, sometimes of great thickness, of green, red, and purple sandstones, grits, shales, or slates, and conglomerates—of marine origin, in the southern portion of the British area, but, in the northern, probably of lacustrine origin. In the latter district, according to the views of Professor A. Geikie, the beds of this division of the series were deposited in several distinct lake-basins. One ("L. Orcadie"), north of the Grampians; a second ("L. Caledonia"), south of these mountains; a third ("L. of Lorne"), a district north of Argyleshire, lying at the entrance of the Great Glen;† and a fourth ("L. Cheviot"), on the southern borders of Scotland.‡ These deposits were derived from the waste of the adjoining lands formed of the metamorphosed beds of the Highland mountains, but how far they extended in the direction of the Scandinavian promontory is altogether uncertain, so that the eastern limits of these basins must be left undefined.

Relations to the adjoining Formations.—Throughout the British area the Upper Silurian beds are unconformable to the Lower Silurian, and in some cases, as in Shropshire, they rest directly on Cambrian beds. In a word, the physical hiatus between the upper and lower divisions of the great Silurian system of Murchison is as marked and complete as it is possible to conceive between any two adjoining sets of strata; and this being the case, it is not to be wondered at that Sedgwick claimed as "Cambrian" all the beds below the Llandovery horizon. After the close of the Lower Silurian epoch, represented by the "Bala Beds," there occurred, over the region in question, terrestrial disturbances of great intensity, accompanied in the north of Ireland and Scotland by metamorphic action.§ Large tracts of the ocean bed were converted into land surfaces, while denudation ensued on a great scale, owing to which the uppermost Lower Silurian beds were washed away, and on the resubmergence of the depressed tracts, these materials were used up in the construction of the basement beds of the succeeding Upper Silurian series. Depression then went on, during which the Wenlock and Ludlow beds were formed under tranquil waters, and towards the close of the latter period, the

* "On a proposed Devono-Silurian Formation," Quart. Journ., Geo. Soc., May, 1882, p. 200; also Trans. Roy. Dub. Soc., vol. i., antea p. 147 (1880).

† "On the Old Red Sandstone of Western Europe." Part I., Trans. Roy. Soc. Edin., vol. xxviii. The margins of these basins drawn on the maps (Plate XXV., Fig. 2), are very much those indicated by Prof. Geikie. He considers that Lakes "Orcadie" and "Caledonia" were never united.

‡ It seems probable that in its earlier condition this lake was connected with the sea, but was subsequently disconnected.

§ That this metamorphism of the Lower Silurian beds of the North British area took place before the Upper Silurian period was first pointed out by Harkness in his paper "On the Age of the Rocks of West Galway," &c. Quart. Journ. Geol. Soc., vol. xxii., and has more recently been insisted on by myself in the "Phys. Geol. and Geog. of Ireland," p. 22 (1878).

great lakes of Scotland and of the north of Ireland, bounded on all sides by metamorphosed strata, were formed, while vast masses of material were accumulated over the region of the south-west of Ireland, but in this instance, probably under the ocean.

Upper Silurian Areas.

The principal areas of this series are to be found along the eastern borders of Wales, extending from the north coast at Conway southwards through Montgomeryshire, Shropshire, Radnor, into Hereford and Monmouth. Isolated portions rise from below the South Staffordshire coalfield, as at Dudley. Eastwards these beds extend under the Cretaceous rocks, and have been proved by borings at Ware* in Hertfordshire, and no doubt, they extend eastwards to the coast. But in Belgium the Upper Silurian rocks are unrepresented, and the Devonian rocks lie in a trough, having the Lower Silurian beds of Brabant on the north, and the Cambrian beds of the Ardennes on the south, against the flanks of which the more recent strata were originally deposited.† As the "Devono-Silurian" beds are in all probability represented by the "Système Gedinnien" (in part at least) at the base of the Devonian Series, they are represented in Plate XXV. Fig. 1, and the sea area is extended over the north of France and Belgium, along the line of this old trough.

The Upper Silurian beds lie along the southern flanks of the Cumberland mountains, having a southerly dip, and probably extend eastwards under the Carboniferous rocks to the coast. They again occur along the flanks of the southern uplands of Scotland, where they were probably separated from the sea, and towards the close of that epoch the area was converted into a lake, in which were deposited the beds of the Devono-Silurian series (Lower Old Red Sandstone) near St. Abb's Head.

In Ireland, Upper Silurian Beds occur in Dingle (Kerry), passing upwards into the Devono-Silurian, or Dingle Beds;‡ they also occupy considerable tracts on both sides of Killary Harbour and the shores of L. Mask; and they are again found forming a small tract on the borders of Roscommon and Sligo. The areas of the Devono-Silurian beds have already been stated.

Distribution of Land and Sea.—As will be seen by referring to the map (Fig. 2, Plate XXV.), the land areas of the region now under description lay both towards the north and towards the south, between which there was a gulf of moderate depth extending over the region of the south of Ireland, England, and the north of France, under which the marine strata were deposited. This gulf threw out an arm towards the north, but how far it stretched beyond the eastern coast-line it is impossible to say. The land area of the north was probably a prolongation of the Scandinavian promontory, while large tracts of the Atlantic to the westward formed continuous

* Mr. R. Etheridge, F.R.S., *The Times*, 19th May, 1879.

† Dr. Mourlon, Géol. de la Belgique, t. 1, p. 54.

‡ Expl. Mem. Geol. Survey, Sheets 160 and 170.

land with the northern Highlands of Scotland and Ireland. The western and northern limits of this land area are incapable of definition; it may have included isolated basins besides those we are able to identify in North Britain. At the commencement of the period we are now dealing with, land prevailed to a much greater extent than that shown in the map, but as time went on, the areas of the sea and inland lakes were extended down to the close of the Devono-Silurian period.

Plate XXVI.

The Devonian Period.

The epoch represented in Figures 1 and 2, Plate XXVI., is that ranging through the Lower and Middle Devonian stages, embracing the beds of the "Lynton," "Hangman," "Ilfracombe," and "Morthoe" divisions of Devonshire, and those lying between the Système Gedinnien, and the Calcaire de Frasne of Belgium. This series, several thousand feet in thickness, is entirely marine. It is laid open in North and South Devon in England, passes below the Cretaceous rocks of the Thames valley, and re-appears in numerous sections along the river valleys of Belgium, such as those of the Sambre, the Meuse, and the Ourthe, as well as along the valley of the Rhine and its tributaries. In a somewhat altered form it occupies a large tract of country bordering the valleys of the Usk and the Wye, in Monmouthshire and Herefordshire, and is generally, but erroneously as I believe, called by the name of "Old Red Sandstone." These last-named beds, I consider to have been deposited in an estuary, bounded towards the north-west and north-east by Silurian lands, but opening southwards into the sea, in which the Devonian beds were being contemporaneously formed. I have, therefore, called these beds "Estuarine Devonian."* From the remainder of the British Islands, including the whole of Ireland and Scotland, the Lower and Middle Devonian beds are absent, owing to causes which I shall presently endeavour to explain.†

Nature of the Devonian Beds.—From what has been said, it will be inferred that the Devonian beds south of the Severn differ in some characters from their representatives north of that river.

South of the Severn the formation consists of beds of grit, shales, and limestone, in alternating masses, highly fossiliferous, and yielding remains of molluscs, corals, and crinoids, and some plants.‡ North of the Severn the beds consist of red and

* "On the Relations of the Rocks of the South of Ireland to those of North Devon, &c."—Quart. Journ. Geol. Soc., May, 1880, p. 268. The term used in this paper is "lacustrine." I have since preferred the term *estuarine.*

† As I have shown in the paper above referred to.—*Ibid.*, pp. 264 and 270–3. Mr. Etheridge in his Presidential address expresses his concurrence in my views.—Quart. Journ. Geol. Soc., May, 1881, p. 193, *et seq.*

‡ Mr. Etheridge has given a complete account of the fauna of Devonshire in his Presidential address, *supra cit.* He enumerates no less than 235 species as occurring in the Middle Devonian beds of South Devon.

gray marls, with earthy calcareous bands ("cornstones"), and red or purple sandstones. Fish remains are present in the cornstones, but some examples of *Lingula* in the lower beds, and of *Serpula* in the upper, are all the evidences of invertebrate life which, up to the present, they have presented to us.

In South Devon the limestones are more massive, but it is not till we examine the sections in the Meuse and Ourthe, in Belgium, that we are able to appreciate the extent to which marine limestones were developed at this period.

Relations with the adjoining Formations.—Confining our attention to the region of the south of England, the Devonian strata may be considered as forming a complete connecting series with the Upper Silurian and Devono-Silurian beds below and the Carboniferous beds above. Over this region, deposition of sediment appears to have proceeded with but few interruptions, of which none are marked by visible physical breaks. After the close of the Silurian period, depression went on, and various kinds of sediment were formed over the floor of the sea-bed, during slow subsidence over this area. Meanwhile the fauna of the previous period, modified as regards species, but largely similar as regards genera, re-appeared under new forms; and as Mr. Lonsdale long ago observed, presents generally a *facies*, intermediate between that of the Carboniferous, on the one hand, and of the Silurian, on the other. Mr. Etheridge recognises about 550 species as belonging to the British Devonian group.

Absence of Devonian Beds in the North and West of the British Isles.—The absence of representatives of the marine Devonian beds of the south of England over the Irish and Scottish areas is a circumstance which, in my opinion, can only be satisfactorily accounted for in one way, namely, that these areas had been elevated into dry land during the time that the south of England and adjoining continental regions were submerged beneath the waters of the Devonian sea, and became the receptacles of Devonian sediment.* As confirming this view we have the fact that the Upper Devonian, or Old Red Sandstone proper, is everywhere unconformable to the beds on which it rests in Ireland and Scotland, whether these belong to the Devono-Silurian or still older formations.† There is, therefore, in these countries a gap, or hiatus, of a very decided character, which is not the case in Devonshire, where the whole series, from the top of the Silurian to the base of the Carboniferous series, is complete. This northern and western hiatus is, in fact, filled up in Devonshire owing to the presence of the Lower and Middle Devonian beds, which are absent in Ireland and Scotland.

* This view was first proposed in the Geological Magazine, and was afterwards more fully unfolded in the paper above cited, and in the Trans. Roy. Dublin Soc., vol. i., antea p. 147, &c.

† This is distinctly enforced by Sir R. Griffith as regards Ireland, and is exemplified in many sections, especially those of the Dingle promontory; and by Professor Geikie as regards Scotland. There may, also, be a slight unconformity at the base of the yellow sandstone in S. Wales, in keeping with that of the adjoining Irish area.

The unconformity between the Upper Devonian Sandstone (or Upper Old Red Sandstone), and the Devono-Silurian beds (*i.e.* the "Dingle beds" of Ireland, and the "Lower Old Red Sandstone" of Scotland), indicates that after their deposition these beds were subjected to disturbances, were elevated into land surfaces, and exposed to denudation. In this position they remained throughout the Lower and Middle Devonian periods, and were only resubmerged when that of the Upper Devonian set in. Plate XXVI., Fig. 2, represents the period of elevation of the west and north of the British Isles, and of the concurrent depression of the region to the south.

It is probable, also, that the centre and north of France (Normandy, Britany, and the Ardennes), were in a condition of land-surfaces during the deposition of the Lower and Middle Devonian beds, as these everywhere rest, and with varying geological horizons, against the older formations of which this part of France is largely formed. We must also recollect that the whole area of the south of the British Isles, and of the adjoining parts of the continent, has undergone enormous lateral compression, in a north and south direction, owing to which the originally horizontal Devonian and Carboniferous beds have been crushed into numerous sharp foldings and flexures, lying along approximately east and west axes, and that these extend from the extremity of Kerry and Cork through Devonshire, under the Thames valley, and reappear in France and Belgium, and as far as the banks of the Rhine.

If, therefore, we wish to realize the geographical position of the Devonian beds as originally deposited, we must reduce these flexures of the beds to the horizontal position, in which case the present apparently narrow trough running across the south of England and north of France would be spread out to probably almost twice its present width.*

Distribution of Land and Sea.—On the above grounds, therefore, I have represented in Figure 2, the whole of the western and northern portions of the British Islands, with the adjoining portions now covered by the ocean, as land during the Middle Devonian period. Contemporaneously with this the sea extended over the south of England, and eastwards into Germany, under the waters of which were deposited in England the fossiliferous limestones of Ilfracombe and Plymouth; in Belgium, the "Calcaire de Givet;" and in Germany, the "*Stringocephalus* limestone." Once we thoroughly understand the physical relations of these different areas, the reasons for the present distribution of strata become clear.

* The flexuring of these beds, as laid open along the Meuse, is very well shown by M. Gosselet in a drawing, as copied by Dr. Mourlon, in the "Géol. de la Belgique," t. 1, p. 56. As the average angle of inclination exceeds 45°, the original length would have been in this case more than twice the present.

Plate XXVII.

Old Red Sandstone and Lower Carboniferous Periods.

In order to save the engraving of a separate plate, I have endeavoured to include the above sets of strata in one pair of maps, although the Old Red Sandstone is a member of the Upper Devonian Series, rather than of the Carboniferous. This is proved by the occurrence of Old Red fishes (*Coccosteus*, *Pterichthys*, *Asterolepis*, &c.), together with plants (*Adiantites Hibernicus*), and fresh-water molluscs (*Anodonta Jukesii*), in the beds of this formation in Ireland. In many districts, however, the Old Red Sandstone appears to be conformable to the overlying Lower Carboniferous beds, while unconformable to all strata older than the Middle Devonian beds, and as these are only present in the south of England, Belgium, and France, the Old Red Sandstone is elsewhere unconformable to the strata on which it reposes.

The strata included in Plate XXVII., range from the Old Red Sandstone or Conglomerate to the top of the Carboniferous Limestone. At the commencement of the deposition of these beds the greater part of the area now described existed as land. But as time went on, the British area became depressed, and the sea gradually gained on the land; so that, at its close, only the northern and western tracts were unsubmerged, together with portions of the border districts of Scotland. The Cumberland mountains, and a tract ranging* from North Wales, Shropshire, and the centre to the east of England was also unsubmerged. Over the submerged areas the Lower Carboniferous strata were deposited; from the unsubmerged districts they are absent. Throughout South Staffordshire, parts of Salop, Leicestershire, and Warwickshire, the Upper and Middle Carboniferous beds rest directly on the Silurian or Cambrian beds.†

Nature of the Old Red Sandstone.—The Old Red Sandstone is found over the S. of Ireland in the form of a massive conglomerate, forming fine escarpments in the Commeragh and Dingle mountains, and passing upwards into finer red sandstones, and beds of flagstone and shale. The uppermost beds, called the "Kiltorcan beds," contain fish-remains, a fresh-water mussel (*Anadonta Jukesii*), and plants. They are lucustrine deposits over the area of the south of Ireland, and mark the upper limit of the Old Red Sandstone.

In South Wales, along the northern margin of the coal-basin, the Old Red Sandstone forms bold cliffs, rising from below the Carboniferous limestone and shale, and consists of yellow sandstone and conglomerate. In North Devon, it is

* It is possible that the sea may have spread between North Wales and the Wicklow mountains during this time.

† South of Halesowen, the Upper Silurian beds were penetrated by a coal-shaft under the Upper Coal-measures, and at Dudley, Forest of Wyre, Shrewsbury, &c., the Upper Coal-measures rest on Lower Palæozoic beds.

represented by the "Pickwell Down sandstone,"* occupying a similar position below the "Pilton and Marwood beds." In Belgium and France, it is represented by the "Psammite du Condroz," of the Upper Devonian Series, and in Scotland, by Red Sandstone and Conglomerate, unconformable to the "Lower Old Red" (or Devono-Silurian) beds. It is scarcely represented in the north of England.†

Lower Carboniferous Beds.—These immediately succeed the "Kiltorcan beds," in the south of Ireland, and there consist of gray grits and slates ("Coomhola grits") passing upwards into the "Carboniferous slate" and limestone. In the north of Ireland, the "Coomhola beds," &c., are represented by massive yellowish grits and shales, with a conglomerate base. The Carboniferous limestone forms the greater portion of the central plain of Ireland. In Scotland the base of the Carboniferous series is called the "Calciferous sandstone," and the limestone is represented by that of the Roman camp near Edinburgh. In the north of England, the "Scar limestone" forms step-like escarpments, and in Derbyshire rises into hills of 2,000 feet, dipping down towards the east and west below the Yoredale beds and millstone grit.

In South Wales the limestone forms a range of fine escarpments along the north of the great coal-basin, resting on the shales, and passing below the millstone grit. In North Devon these shales are represented by the "Marwood," "Pilton," and "Barnstaple" beds, as already stated. The Carboniferous limestone, however, is a debased formation as compared with its representative further north. In Belgium the Carboniferous limestone is nobly developed and immediately underlies the coal formation.‡

The following Table of Synonyms may prove useful :—

TABLE OF SYNONYMS.

	England.	Ireland.	Scotland.	Belgium.†
Middle Carboniferous, . .	Gannister Beds, .	Lower Coal-Measures.	Slaty Black-band Series.	Schistes de Chokier.
	Millstone Grit, .	Millstone Grit, or Flags.	Moorstone Rock.	Absent, in some places as Liége, but present in others.
	Yoredale Beds, .	Shale Series, .	Upper Limestone, and Lower Coal and Ironstone Series.	
Lower Carboniferous, . .	Mountain Limestone.	Carboniferous Limestone.	Roman Camp Limestone.	Calcaire de Dinant.
	Limestone Shale, or Baggy, Pilton Beds.	CarboniferousSlate, Coomhola Grit, &c.	Upper and Lower Calciferous Sandstone.	Schistes de la Famenne.
Old Red Sandstone (Upper).	Yellow Sandstone and Conglomerate. Pickwell Down Sandstone (Devonshire.)	Kiltorcan Beds, Old Red Sandstone and Conglomerate.	Upper Old Red Sandstone.	Psammite du Condroz (lower part.)

* Scient. Trans., Roy. Dub. Soc., vol. i., antea p. 147.—Etheridge, Quart. Journ. Geol. Soc., vol. xxxvii., p. 196.

† For a full account of the representative series given above, see Quart. Journ., Geol. Soc., vol. xxxii. pp. 613–651.

‡ In Belgium the lower coal-measures sometimes, but not always, rest unconformably on the limestone, the millstone grit and Yoredale beds being then absent. This was explained to me by Dr. De Koninck, at Liége.

Distribution of Land and Sea.—At the commencement of the Upper Devonian stage nearly the whole of the centre and north of Ireland, the north of Scotland, the centre and north of England and Wales, were dry land, but in the southern portions of the British Isles and adjoining parts of the Continent there was an area of depression. Over the south of Ireland there appears to have been formed a fresh-water lake, in which the Old Red Sandstone was deposited in the form of shingle and finer sediment drained from off the adjoining lands formed of Silurian and Devono-Silurian beds which had been previously elevated into land over the region of Kerry, Cork, and Waterford. The waters of this lake were inhabited by numerous fishes and the large mussel, *Anodonta Jukesii,* while the adjoining lands were covered by a luxuriant vegetation, the representatives of which are preserved to us in "The Kiltorcan beds." This lake may have extended eastwards into the south of England, but in France and Belgium it gave place to marine conditions, as the representative strata known as the "Psammite du Coudroz" are of marine origin.* In Scotland the yellow sandstone and conglomerate, with *Holoptychius* and *Cyclopteris* (Palæopteris) *Hibernica,* was probably deposited within lacustrine waters.

On the commencement of the Lower Carboniferous stage the sea everywhere occupied the submerged tracts, bathing the sides of the uplands and mountainous parts, and bringing with it multitudes of marine animals, so that the oldest Carboniferous strata in Ireland, England and Wales, and Scotland contain numerous marine forms.† During the subsequent epoch of the Carboniferous Limestone the depression proceeded, and the sea ascended on the flanks of the uplands until only the very highest elevations were left uncovered. Deep sea conditions prevailed over the north and south of England and the centre of Ireland, and here the calcareous beds were formed in greatest thickness and purity through organic agency. A tract of country extending across England, from Shropshire through Worcestershire and South Staffordshire, into the eastern counties appears to have remained as a ridge or land barrier, separating the basin of the north of England from that of the south, as the Lower Carboniferous rocks are absent, or only present as thin marginal representatives along this line of country.‡

In Plate XXVII., figure 2, the relations of sea and land are indicated, as far as possible, during the middle of the epoch of the Carboniferous Limestone.

It is also probable that the old rocks of the north-west of France were unsubmerged, as the little detached coalfields of the centre of that country rest directly on these rocks

* Here it contains marine fossils, such as *Spirifer disjunctus, Rhynchonella pleurodon,* with plants *Lepidodendron notum, Sphenopteris flaccida,* and a variety of *Palæopteris Hibernica.* Mourlon. *Loc. cit.*, p. 88.

† See preceding Table of Synonyms, page 272.

‡ The existence of such a ridge was first indicated by the late Professor Jukes, and subsequently described in "The Coal Fields of Great Britain." The discovery of Carboniferous Limestone at a depth, of 890 feet below Northampton shows that the ridge was south of this spot. Etheridge; Quart. Journ. Geol. Soc., vol. xxxvii., p. 231.

without the intervention of the Lower Carboniferous beds; at the same time, over the region lying along the borders of France and Belgium, the waters of the Lower Carboniferous sea prevailed, and the limestone formation is grandly represented.

Plate XXVIII.

Upper Carboniferous Period.

The Upper Carboniferous strata are the chief depositories of coal in the British Isles and the adjoining continental districts. They are separated from the Lower Carboniferous strata represented in Plate XXVII., by the middle division of the system, including the following in descending order:—*

Middle Carboniferous Series.
1. The Gannister Beds, or Lower Coal-measures.
2. The Millstone Grit, or Flagstone Series of Ireland.
3. The Yoredale Beds, or Upper Shale Series of Ireland.

All the above are essentially of marine origin; those of the Upper Carboniferous series are of estuarine or lacustrine origin, with occasional marine bands at distant intervals.

Nature of the Upper Carboniferous Beds.—The strata included under this head consist of two divisions; the Lower, or Middle Coal-measures, consisting of yellow and gray sandstones, blue and black clays and shales, bands of coal and ironstone. They contain plants, bivalves (*Anthracosia*), and fish remains. The occasional marine bands are to be recognised by the fossils. The Upper Coal-measures consist of reddish and purple sandstones, red and gray clays and shales, thin bands of coal, ironstone and limestone, with *Spirorbis carbonarius*, and fish. These two divisions combined attain, in Lancashire, a thickness of 5,000 to 6,000 feet, but thin away rapidly in the direction of Leicestershire and Warwickshire. In Belgium these beds are also of great thickness, though the uppermost have generally been denuded away.

Distribution of Strata.—The Coal-measures of England and Scotland were originally distributed in two, or possibly three, large sheets, lying to the north and south of a central ridge, ranging from North Wales through Shropshire eastwards.† This I have called the central barrier (Fig. 2). It is uncertain whether it was not connected with the ridge of the Wicklow Mountains across the Irish Channel. This old ridge may be a prolongation of a land area stretching southwards from Scandinavia, and it existed in wider dimensions during the Lower Carboniferous period.‡ It is also uncertain whether the coal-measures of Scotland stretched

* This is a classification proposed in my paper "On the Upper Limits of the essentially marine beds of the Carboniferous group, &c." Quart. Journ., Geol. Soc., Vol. XXXII., pp. 613–651. It has not been considered necessary to prepare a plate of this division, which would be intermediate in its arrangements between Plates XXVII. and XXVIII.

† The evidences of this ridge cannot here be discussed, but the reader is referred to the *Geological Survey Memoir*, "On the Triassic and Permian Rocks of the Central Counties of England;" also to the "Coalfields of Great Britain." 4th edition, p. 520.

‡ Compare Fig. 2, in Plate XXVIII., with that in Plate XXVII.

continuously across the south of Scotland to join those of the north of England. It has been assumed that some of the higher parts of the southern uplands were uncovered by Upper Carboniferous strata, as they certainly were by those of the preceding stage. Nearly the whole of Ireland was originally covered by coal-measures.*

Formation of Coalfields.—Out of the original extensive tracts of coal-measures, almost conterminous with the boundaries of submerged areas shown in figure 2, the existing coalfields have been constructed. As compared with the original areas, their size is small indeed. This is due to the extensive denudations which took place—first, at the close of the Carboniferous period; second, at the close of the Permian period; and thirdly, in still more recent times. Ireland has suffered most of all, owing to the absence of mesozoic strata;† only small isolated patches, monuments of former more extended tracts, have been left behind.

The possible positions of three coal-basins south of the Thames valley are shown in figure 2, very much the positions originally indicated by Mr. R. Goodwin-Austen.‡ The sub-Wealden boring, intended to ascertain the nature of the Palæozoic strata along this tract, unfortunately was stopped before passing into Palæozoic rocks. The position of the coal-measures—proved under the Lias by boring at Burford—is also shown in Figure 1, but it is impossible to determine the form of this coal-basin.

Distribution of Land and Water.—Little need be added to what has already been said on this point. As compared with the Lower Carboniferous epoch, the land areas become contracted owing to subsidence, but the thickening of the strata, both towards the north-west and south-west of England, indicate the existence of extensive tracts of land, and sources of sediment, in those directions.§ The waters which overspread the plains were disconnected from those of the ocean, except at intervals, though possibly at all times bordering on the sea-level of the period.

Plate XXIX.

The Permian Period.

The Permian beds are restricted to the central portions of the British Isles, and apparently were never deposited over any part of the extreme northern, western, or southern districts, or of the adjoining continental areas. According to the view of Sir A. Ramsay, the magnesian limestone of the north of England was formed

* See "Physical Geology and Geography of Ireland," pp. 43, 149, 163. † *Ibid.*, p. 164.

‡ Quart. Journ. Geol. Soc., vol. xi. (1855.) The same author places the line of possible coal-measures under the Thames valley, but the London borings for water do not appear to me to bear out this view. See Map, No. 6, to accompanying evidence before the Royal Coal Commission.

The extension of the Coal-measures beneath newer formations is indicated by the lighter shade in figure 1.

§ See, on this subject, my paper "On Iso-diametric Lines, &c." Quart. Journ. Geol. Soc., vol. xviii. pp. 127–146 (1862).

under the waters of an inland sea, like the Baltic or Caspian, the fauna being exceedingly sparce, as compared with that of the limestones of the Carboniferous period,* and indicative of the absence of open oceanic waters. The region of the magnesian limestone of the north of England appears to have been disconnected with that of the central counties and Shropshire by a barrier ridge, the position of which is indicated in Figure 2. To the south and west of this ridge, only Lower Permian beds are found,† and it is probable that these latter beds are, in the main, lacustrine. The Permian beds of Scotland are restricted to the south of that country, and those of Ireland to the districts of Down, Tyrone, and Armagh.

Nature of the Permian Beds.—Owing to the dissimilarity of the Permian beds lying on either side of the Carboniferous ridge above referred to, I have arranged the Permian strata under two heads or types—those of the "Lancastrian" and "Salopian."‡

The beds of the "Lancastrian type" belong to the north of England, and may thus be described in the west and east of that area :—

Permian Beds of the Lancastrian type.§

	West.	East.	
Upper Division.	Bands of limestone, sometimes magnesian, with red marls. Fossils—*Turbo, Rissoa, Natica, Axinus, Schizodus,* &c.	Marls. Upper Limestone. Marls. Magnesian Limestone.	Fossils, marine.
Lower Division.	Lower Red Sandstone, . . .	Lower Red or Yellow Sandstone.	

On the other hand, the beds of the "Salopian type" are restricted to the west and central parts of England, and consist of a thick series of red and purple sandstones, clays, shales, with calcareous conglomerates and breccias or boulder beds. The typical section occurs at Enville, in Salop.

The boulder beds are exceedingly like those formed by the agency of floating ice, consisting of accumulations of red, stony, clay, with sub-angular fragments of trap, Silurian, and Cambrian rocks, some of which show surfaces slightly glaciated. Professor Ramsay considers that these breccias have been formed in waters filled with floating ice derived from lands lying towards the north-west of the submerged area.|| These accumulations occur in Shropshire, Worcestershire, Staffordshire, Warwickshire, and at Armagh, in Ireland.¶ There are also beds of calcareous

* "Phys. Geol. and Geog. of Great Britain." 5th edition, p. 147.

† Quart. Journ. Geol. Soc., vol. xxv., pp. 171–184; also, "Triassic and Permian Rocks, &c," Mem. Geol. Survey, p. 10.

‡ *Ibid.*, p. 11.

§ The exact representation of the series in Lancashire by that of Durham and Yorkshire (though not identical in character) proves that these beds were originally physically connected across the country, as shown in Fig. 2, Plate XXIX.

|| Quart. Journ. Geol. Soc., vol. xi., p. 189.

¶ "Phys. Geol. and Geog. of Ireland," p. 46, and "Explan. Mem. Geol. of Armagh." Mem. Geol. Survey, sheet 47.

conglomerate formed of pebbles of Carboniferous Limestone. The Alberbury breccia belongs to this formation.*

Distribution of Land and Water.—It is probable that during the Lower Permian period two distinct basins were formed, lying on either side of the dividing ridge, both being inland lakes, or only very slightly connected with the sea. Into these lakes were carried beds of fine sand, clay, and gravel by the streams draining the adjoining lands formed of older Palæozoic rocks. On the commencement of the Upper Permian period there was a subsidence over the region of the northern lake, and the waters of the sea flowed in, bringing with them representatives of a marine fauna, and in which the great limestone beds of the north of England were deposited. These beds are not represented over the centre and west of England, in which the beds belong exclusively to the lower division of the Permian system, known in Germany by the name of "Rothe todte liegende."

Plate XXX.

The Triassic Period.

The terrestrial movements, accompanied and followed by extensive denudation which ensued at the close both of the Carboniferous and Permian periods, produced marked changes in the distribution of the strata of the Triassic period as compared with that which preceded it. There is a complete discordance between the Mesozoic and the Upper Palæozoic strata, so that the beds of the New Red Sandstone, or, in its absence, those of the Keuper Marl, rest indifferently on various members of the Permian, Carboniferous, or even older rocks.

Amongst the physical changes brought about at the close of the Carboniferous period, was the formation of a ridge of Palæozoic rocks, under the south of England, of which the Mendip Hills is the western prolongation, and against which both on the north and on the south the Mesozoic strata wedge out. Under the east of England, this ridge is in part composed of the older Silurian or Cambrian beds which occupied that district during the Carboniferous and Permian times; but it was considerably extended at the close of the Carboniferous period, and forms a portion of that great system of flexured and folded strata which range from the south of Ireland, through the south of England and Wales, into France and Belgium, and beyond the Rhine. Another ridge of great importance in physical geology is of that known as the "Back-bone of England," which ranged from Derbyshire northwards, and was developed at the close of the Triassic epoch. It is formed of Carboniferous rocks.

As I showed some years ago, the Triassic strata attain their greatest development in Lancashire and Cheshire, and become attenuated in a south-easterly direction. This is due partly to the position of the old Palæozoic ridge above

* Murchison, "Silurian System," p. 83

referred to, and also partly to the decrease of sediment as we recede from the old lands which were the source of that sediment.* From this it may be concluded that the land of the period lay to the north and west of the British Isles. It is also probable that Normandy and Brittany were portions of a land surface at the same period. The numerous beds of breccia and conglomerate in the Triassic strata of Devonshire indicate the proximity of land which may have included portions of Cornwall.† In Ireland, the Trias is only represented in the north-east of the country; and in Scotland, at the extreme south, and in the coast of the Moray Firth, near Elgin. It is probable that these countries were, over by far the greater part, in the position of land surfaces during the Triassic period.

Nature of the Triassic Strata.—The Trias of Britain consists only of two divisions. The Bunter, or New Red Sandstone below, and the Keuper, or New Red Marl above. The intervening marine division of the Muschelkalk being absent in Britain.‡ The Bunter division consists of red sandstone and conglomerate; the Keuper of red and variegated marls and sandy shales, containing gypsum and rock-salt, with beds of sandstone and conglomerate at the base. Their basement beds are, in reality an old shingle beach, formed around the flanks of the unsubmerged lands of the period.

In order to account for the absence of the middle division in Britain, I have suggested that during the formation of the Muschelkalk in Europe, the British area was converted into a land surface. The slight unconformity of the Bunter to the Keuper division, and the eroded surface which the former often exhibits, go to confirm this view.

It is probable that, as suggested by Sir A. C. Ramsay, the Triassic strata of Britain were deposited within the margin of an inland sea or lake. The boundaries of this lake towards the north and west are inferential; those along the old ridge of the south of England have been partly determined by the aid of recent borings of the strata; these borings may be briefly described in the following order:—

1. Scarle near Lincoln. The Triassic strata were reached at a depth of 141 feet, and were found to be 1359 feet in thickness.§ The next (2), was at Northampton, at which the Carboniferous Limestone (as determined from the fossils by Mr. Etheridge), was pierced a short distance below the bottom of the Lias, at a depth

* "On the South-Easterly attenuation of the Lower Secondary Rocks of England." Quart. Journ. Geol. Soc. vol. xvi. p. 63 (1860).

† These beds, including the Budleigh Salterton conglomerate, have been described by Buckland, Conybeare, and Murchison. The lower breccias were considered by these authors to be of Permian age. The section along the coast has been more recently described by Dr. Hicks, Mr. Ussher, and Mr. H. B. Woodward; the last of whom gives a good summary of the views of himself and previous authors. "Geol. Eng. and Wales," p. 136, et seq.

‡ "The Triassic and Permian Rocks of the Central Counties." *Mem. Geol. Survey.* pp. 66, and 106.

§ "Coalfields of Great Britain," 4 ed., p. 261.

from the surface of 890 feet;* the position of this boring is evidently close to the original margin of the Trias. The next (3), was at Ware, in which the Wenlock beds were entered beneath the Gault, so that the position of this boring is considerably south of the original margin of the Trias; on the other hand (4), at Burford, the Triassic strata were passed through before the Coal-measures were reached, and they are also inferred by Professor Prestwich to exist under Oxford, as the water from St. Clement's well is highly impregnated with chloride of sodium. From these data the concealed line of the old ridge can be approximately drawn, while the relations of the Secondary strata along the margin of the Mendip Hills and Somersetshire coalfield, enable us to determine its position there with certainty.†

Distribution of Land and Water.—The land of the period appears to have lain to the north-west, north-east, and south of the British Isles. The Highlands of England, Scotland and Ireland, were certainly in the position of land, and contributed to the sediment poured into the lacustrine area. In the south the submerged area was connected with that of Normandy and Brittany; but land probably lay over the region of Central and Western France. On the whole, the Triassic period over the region now described, was one in which elevation of land was at its highest at the beginning, and at its lowest towards the close, when the waters of the ocean invaded the tracts covered previously by those of large lakes.‡

Plate XXXI.

The Jurassic Period. (*Including the Rhætic, Liassic, and Oolitic Divisions.*)

At the close of the Triassic period the waters of the ocean invaded the tracts previously covered by lakes and estuaries. The influx of these waters is indicated by the fauna of the Rhætic (or Penarth) beds, which is marine, but indicates littoral and shallow water conditions. Along with *Avicula contorta,*§ *Modiola minnima, Pecten Valoniensis,* and *Carduim Rhæticum,* there are remains of insects, fishes, and saurians; but none of cephalopods, whose habits require an open sea. With the commencement of the Lias, however, there occurred a general subsidence of the British and adjoining European area, upon which the sea established its supremacy over all but the elevated mountainous tracts ranging from Scandinavia into Britain. The waters brought with them great shoals of

* *Supra cit.* 231. The late Mr. Samuel Sharp has also described this remarkable boring.

† This concealed ridge has been well described by Mr. Taylor in "By-paths of Nature."

‡ Ramsay, "Phys. Geol. and Geog. of England," 5th edi., p. 155.

§ First described by General Portlock, in his "Geology of Londonderry, &c.," and afterwards identified by Dr. Wright, in Gloucestershire. Quart. Journ. Geol. Soc., vol. xvi.; and Mr. Bristow, at Aust-Cliff and Penarth, on the banks of the Severn.

cephalopoda, nautili, ammonites, and cuttlefishes, as well as other inhabitants of the deep. Saurians abounded both in air, land and water, and during the Oolitic period, living forms both vertebrate and invertebrate were excessively prolific. Although deep sea conditions generally prevailed throughout the Jurassic period owing to subsidence preceding more rapidly than deposition of sediment, yet, occasionally shallow lagoons were formed, such as those represented by the Stonefield and Collyweston beds; and towards the close, those of the Portland and Purbeck beds.

Nature of the Jurassic Strata.—Considered generally, the Jurassic system consists of two great divisions. The lower (that of the Lias), being argillaceous; the upper (that of the Oolite), calcareous. But this description requires modification, as the Liassic beds contain in some places calcareous or arenaceous strata, and the Oolite great beds of clay and sand.* The different divisions, as Dr. Wright has shown, are characterized by different species of ammonites, which range not only over the English area, but into the Jura mountains, Switzerland and Germany. The total thickness of the group may be taken at 3,000 feet, of which the Liassic beds reach about 1,000 feet.

Distribution of Land and Water.—How far the strata of the Jurassic group originally extended, and to what extent the higher elevations of the British Isles were covered by the waters of the Jurassic sea is a problem not easy of solution. At the same time, we have several indications of the former extension both of the Liassic and Oolitic strata which go far to guide us towards some definite conclusions on this question. In the first place, having regard to the great thickness of these strata along the northern and western margins, we infer that they originally extended far beyond their present limits, and that they covered all the comparatively low-lying tracts of England now occupied by the Triassic strata. The existence of Rhœtic and Liassic strata in the north-east of Ireland, and in the Vale of the Eden, near Carlisle, prove the original continuity of the Liassic sea with that which flowed over the central plains. These beds are also found skirting the western coast and islands of Scotland,† and on the east, the shores of Dornoch Firth. We may well suppose, therefore, that the Jurassic sea bathed the flanks of the Irish and Scottish Northern Highlands, as shown in the map (Plate XXXI. Fig. 2). The western limits of the tract running along the Western Highlands of Scotland, are in part defined by the mountains of Derry, Donegal, and the ridge of the outer Hebrides. The Atlantic area was probably distributed into ridges or islands, with intervening sea-lochs and basins, of which Rockal, Bus (or Busse), and several of the little islets or sunken rocks in that portion of the Atlantic between lat. 10° and

* I do not consider it necessary to enter into details which may be found in any of the text-books of Geology.

† As shown by Murchison, Geike, and Bryce. Quart. Journ. Geol. Soc., vols. xiv. and xxix.

30° W. may be the modern indications.* The Oolitic beds of Brora—with coal—indicate marginal conditions along the north-eastern coast of Scotland;† while, as Professor Judd has shown, these beds are well represented in Sutherlandshire, and were deposited close to land; so that it is probable the Oolitic sea stretched from the north of England round the eastern coast of Scotland, during and after the period of the Lower Oolitic.

It is altogether uncertain whether the Oolitic strata were formed over the north of Ireland; but, if so, they had been swept away by denuding agencies previous to the Cretaceous period, as no strata of the Jurassic group higher than the lower beds of the Lias are found in that country.‡ It is probable that the whole of the south and west of Ireland were in the condition of land during this time.

Whether any portion of the central ridge (or "Backbone,") of the North of England remained unsubmerged during the Oolitic period is uncertain; but that the sub-Cretaceous ridge was in part (at least) uncovered by strata of this period, may be considered as highly probable, owing to the entire absence of representatives of the Jurassic period in the borings of Ware, Turnford, and London. On the other hand, the sub-Wealden boring near Battle, in Sussex, has shown that, to the south of this ridge, the Jurassic sea prevailed, and was deep; as the Kimmeridge clay was entered at a depth of 255 feet, and extended down to 1,769 feet, below which the coralline Oolite was penetrated to a depth of 51 feet.§ The sea of the south of England stretched southwards into France, and probably had its western margin in Devonshire, Cornwall, and Normandy, while its northern limits stretched from the Thames valley eastwards, to the south of Ostende, where (as already stated), the Lower Silurian rocks are found beneath the Cretaceous.

It will thus be seen that during the period now under consideration, the British Isles constituted a group of small islands surrounded by waters which overflowed the lower tracts and extended into the Atlantic. On the other hand, part of the Atlantic Ocean itself was to some extent in the position of dry land, from which the sediment constituting the sands and clays of the Jurassic series were probably derived.||

* Geikie's Geol. Map of Scotland. Dr. W. Frazer, of Dublin, has shown a map about 200 years old, by Tassin, the Geographer Royal of France, in which "the Sunken Land of Busse," now only a rock, is shown, and which was coasted by one of Frobisher's ships for three days. As Dr. Frazer has shown, the North Atlantic appears to have undergone considerable subsidence in even recent times, of which the traditional island of Hy Brasil, off the coast of Ireland, is an illustration. Journ. Roy. Geol. Soc. Irel., vol. v. (n. sec.) p. 128.

† Murchison, Trans. Geol. Soc., Lond., vol. ii. 2 ser., p. 393.

‡ "Phys. Geol. and Geog. of Ireland," p. 52.

§ Third Report of the Sub-Wealden Exploration Committee, by Messrs. H. Willett and W. Topley (1875), pp. 346-7.

|| This view I have developed in my paper on "The South-Easterly Attenuation of the Lower Secondary Rocks." Quart. Journ. Geol. Soc., vol. xiv. (1860.)

Plate XXXII.

The Cretaceous Period.

At the close of the Jurassic period, the bed of the sea was elevated into dry land over the British area, and re-distributed into lakes and estuaries, with surrounding tracts of lands formed of Jurassic and older formations. During this epoch, denudation of the strata proceeded, while beds of shale, sandstone, and limestone (representing the Purbeck formation), were deposited over the floors of the lakes. Later on, these conditions gave place to others, when the Wealden beds, restricted to the south-east of England, were deposited at the mouth of a river, or rivers, draining the lands lying towards the north and west.

The interval of the Purbeck and Wealden epochs may be considered as a sort of interregnum between the great Jurassic period on the one hand, and that of the Cretaceous on the other. It was, however, one of considerable duration; and on the Continent is partly represented by the "Maestritch Beds" of Belgium, and in Western America, by the "Laramie Beds" of Colorado.*

Upon the commencement of the Lower Cretaceous epoch, beds of sand and gravel, now known as the "Lower Greensand" formation, were deposited in a shallow sea, and at no great distance from the land, which lay—both to the westwards (in the region now forming Cornwall, Devon, and Wales), and also along the line of the Thames valley—where the old ridge of Silurian, Devonian, and Carboniferous rocks was still uncovered by sediment.†

After the deposition of the Lower Greensand, there was another slight elevation of the sea-bed, and much of this formation, with portions of those below it, were swept away; but upon the commencement of the Upper Cretaceous epoch, subsidence again set in, which continued till the close of the Cretaceous period, at which time the south and centre of Europe, and all but the very highest elevations of the British Isles, were submerged beneath the waters of an ocean which must have extended eastwards from the Atlantic into Asia, and which not only occupied the basin of the Mediterranean, but the plains of France, Germany, Italy, Spain, and of Northern Africa.‡ This epoch of greatest submergence is represented in Plate XXXII., Figure 2.

The interval of land, lacustrine, and estuarine, conditions between the Jurassic and Cretaceous periods, together with the concomitant denudation, has resulted in

* According to Dr. Hayden, and Prof. Cope. Bull. U.S., Geol. Surveys, vol. v., No. 1 (1879).

† The absence of the Lower Cretaceous beds in the Crossness boring is evidence of this, as also the beds of conglomerate occurring in the Lower Greensand of Oxfordshire and Wiltshire. In the fourth edit. of the "Coalfields of Great Britain" (p. 354), I have given a section showing the position of this ridge under London, from which it will be seen that the Palæozoic rocks were not completely covered till the period of the "Gault Clay."

‡ It is probable that only a core of Palæozoic rocks of the Alps and Pyrenees were left unsubmerged at this period, but Scandinavia was probably a land area.

producing a complete unconformity of stratification between the formations themselves, along with which there is a complete change in the fauna; so much so, that with the exception, perhaps, of some *Foraminifera*, no species passes from the Jurassic into the Cretaceous rocks, and of 300 Lower Greensand species, only about 20 per cent. survive into the Upper Cretaceous series.*

Nature of the Cretaceous Strata.—Speaking generally, the Lower Cretaceous strata consist of gravel, sands, and clays, of sedimentary origin, indicating a process of formation not far remote from the land of the period, and in a sea of no great depth. They are altogether absent on the borders of Devon and Dorset, where the Upper Greensand rests directly on the New Red Marl and Lias. The Upper Cretaceous strata indicate the prevalence of oceanic conditions (during the later stages) in the formation of the chalk, which is a white limestone composed in the main of shells of *Foraminiferæ*, and containing molluscs, crinoids, and echinoderms in great numbers. Spicules and casts of sponges are common, and are often found enclosed in flints.

The beds and nodules of flint of the Upper Chalk, are due to a process of pseudomorphism, whereby the free silica in the waters of the ocean has, from time to time, been consolidated around some body, such as an echinus, a sponge, a shell, or other foreign body, and has replaced the original carbonate of lime of which the body itself was formed, or by which it was enveloped.† The Upper Greensand formation, at the base of the Chalk, has been shown by Ehrenberg to be formed of the casts of Foraminifera preserved in silicate of iron.‡ Similar casts were brought up from deep waters in the Indian Ocean by the officers of the "Challenger" expedition.

With the Upper Cretaceous beds commences the appearance of Dicotyledenous plants, both in Europe and America,§ giving a perfectly new aspect to the flora of the world, or as it has been expressed by Dr. Oswald Heer, "introducing a new fundamental conception of the vegetable kingdom."

Distribution of Land and Sea.—At the commencement of the Cretaceous period, the British area was probably almost entirely in the condition of dry land, and was but slightly submerged during the formation of the Lower Greensand. Professor Ramsay considers that this submergence was so slight that the Oolitic strata, which then extended far to the west into the borders of Wales, were not entirely submerged.‖ After its deposition, the land was tranquilly raised out of the sea, and subjected (along with the older strata) to atmospheric waste.

The deposition of the Gault in our area, first took place on the surface of a

* Ramsay. *Supra cit.*, p. 217.

† The process has been fully explained by the late Dr. Bowerbank, and more recently by Professor Rupert Jones, F.R.S.

‡ "Ueber den Grünsand." Abhand. der K. Acad. der Wissenschaft, zu Berlin, 1855, p. 85.

§ Viz. :—At Aix-la-Chapelle, and in America, from the Rocky Mountains to the Arctic Regions at Noursoak.

‖ *Supra cit.*, p. 230.

country that was being gradually submerged, and part of the sediment was distributed over the Lower Greensand, or along the flanks of the little ranges of hills formed out of it, and part over the underlying Oolitic strata. As time went on the submergence increased, and more rapidly than the filling up of the sea-bed by the accumulation of Upper Cretaceous strata. During the period of the Upper Chalk, the submergence reached its maximum. I have already stated the great extent of the existing land surface over which the ocean waters spread in the centre and south of Europe. The submergence of the north of Ireland, and of, at least, the borders of the Scottish Highlands is indicated by the presence of the Chalk and Upper Greensand overlying the Lias in County Antrim, and by similar beds in the Isle of Mull, and at Bogingarry, in Aberdeenshire.* To what extent this submergence progressed is of course uncertain, but we may assume that the more elevated districts formed of Palæozoic rocks were not completely under water, while it is highly probable that land lay over a large tract of the Atlantic, extending westwards from the Scandinavian promontory, as I have endeavoured to represent in Figure 2, Plate XXXII. The highlands of Cumberland, Wales, and Ireland were also, in all probability, in the condition of land surfaces. It is more uncertain what was the condition of such tracts as those of Dartmoor, in Devonshire, the southern uplands of Scotland and the Isle of Man.†

The relations of land and sea shown in Figure 2, are those which are supposed to have existed during the formation of the Upper Chalk. The more deeply submerged areas, extending into France and Belgium, are shown by a deeper tint of blue—the more elevated unsubmerged mountain tops by correspondingly deeper tints of brown.

Plate XXXIII.

The Tertiary Period (Eocene, Oligocene and Miocene Divisions).

The Tertiary strata of the British Isles are restricted to the southern parts of England, the north-west of Scotland, and the north-east of Ireland. I have represented on the map (Figure 1, Plate XXXIII) the position of the deposits belonging to the Eocene, Oligocene, and Miocene divisions. In dealing with the physiology of these deposits we will consider the Eocene and Oligocene in the first instance, and the Miocene in the second.

* As shown by Prof. Judd (Quart. Journ. Geol. Soc., vols. xxxix. and xxx). Professor Judd considers that the Cretaceous beds once "extended over large portions of Scotland," from the presence of chalk flints beneath the basalts of Mull, &c., as well as from the occurrence of detached outliers both on the mainland and in several of the western islands. *Ibid.*, vol. xxix., p. 105.

† The distribution of land and sea, as shown in Figure 2, very nearly agrees with the ideas stated by Prof. Sir A. Ramsay in his "Physical Geography of Great Britain," 4th edit., p. 257.

(1.) *Eocene and Oligocene Strata.*—These deposits occur chiefly in two separate tracts or "basins"—that of London, and that of Hampshire and the Isle of Wight. They also occupy a large tract of the adjoining Continent. Originally these were connected in one great sheet ranging into the centre of France, and extending in England far beyond their present limits, both northwards and westwards, but *how far* it is extremely difficult, if not impossible, now to determine. Their disseverance into three separate tracts took place during the Miocene period; when—by the contraction of the earth's crust, the elevation of the ground now occupied by the Weald of Sussex into an anticlinal arch bordered by corresponding depressions, and the subsequent denudation of the strata—the London Tertiary basin was separated from that of Hampshire, and the Cretaceous strata, with the underlying Wealden beds, were brought to light.* At the same period, by denudation along the Straits of Dover, the Paris Tertiary basin was dissevered from that of London. This process of denudation has proceeded ever since, and has affected not only the Tertiary but the subordinate Secondary strata of the Cretaceous and Jurassic series: so that vast tracts of Chalk, Greensand, Oolite and Lias have been denuded away by atmospheric agencies from the commencement of the Miocene epoch downwards, and the boundary scarps have receded further and further in the direction of the dip of the strata to their present positions over the whole of the south of Europe, and the adjoining district of France and Belgium.

During the formation of the Eocene and Oligocene beds, the north and west of the British Islands was, in all possibility, in the condition of dry land. It is probable that Ireland was joined to England and Scotland by a tract of Cretaceous rocks mantling round the hills of older formations. To the south of this tract of land the waters of the Tertiary sea spread, extending over the north and centre of France and Belgium, in which direction they become more limpid and free from sediment than during the epoch represented by the London clay, so that while beds of clay were being deposited over the area of the estuary of the Thames, others of pure limestone with *nummulites*† were being formed over the area of the Paris basin.

Nature of the Eocene and Oligocene Strata.—The oldest beds consist of gravels, sands, and clays, of marine or fluvio-marine origin.‡ These are succeeded by the London clay, a blue and brown stiff clay, with *Septaria*, about 500 feet in thickness, and of marine origin. This formation thins away in the direction of the Isle of Wight. The succeeding Middle Eocene beds consist of the Bagshot sands and Bracklesham beds, of estuarine origin, and the upper, of the Barton clay, of marine origin, 300 feet in thickness. The "Oligocene beds" of Beyrich

* Ramsay: "Phys. Geol. and Geog. of Great Britain."

† In the lower part of the "Calcaire grossier" of Paris there are three species of *Nummulites* abundant, viz.: *N. levigata, N. scabra, N. Lamarki*, which serve to show that it corresponds to the epoch of the formation of the great Nummulite limestone of the South of Europe, &c. One of these, *N. levigata*, occurs in the Middle Eocene beds of England.

‡ The Thanet Sands and "Woolwich and Reading Beds" of Prestwich.

have been shown by Professor Judd to be present in the Isle of Wight,* and consist of alternating sands, clays, shales and limestones of marine and estuarine origin.

All these beds were deposited either at the mouths of rivers flowing from the north and west into a sea, which was generally open in the direction of France, but often very shallow, and sometimes converted into estuaries and even lakes of limited extent. Oceanic water, such as that of the Atlantic, probably never occupied the area in question. The fauna indicates successive stages of depression or elevation, and the alternation of fresh water, estuarine, or marine conditions.

Distribution of Land and Sea.—I have already to some extent dealt with this subject, and will, therefore, only here observe that as a long interval of time elapsed between the formation of the Upper Chalk and of the Lower Eocene strata,† during which land conditions prevailed over the British area, much of the Chalk formation itself was denuded away; and consequently the Tertiary beds are unconformable to the Cretaceous, and rest sometimes on higher, sometimes on lower strata of that formation.

The position of the northern limit of the sea margin, even during any given epoch of the Tertiary period, is a question of much uncertainty. In Figure 2, Plate XXXIII, I have attempted to show the physical geography of the epoch of the London clay, when the sea had its greatest extension over the area here described. At the same time, I have considered it necessary to leave a considerable tract of uncoloured debateable ground between the respective margins of land and sea.

(2.) *Miocene Strata.*—With the exception of some lacustrine beds of gravel, clay and lignite at Bovey Tracey in Devonshire, all the British representatives of the Miocene epoch are restricted to the north-east of Ireland, and the west coast and isles of Scotland, and are of volcanic and lacustrine origin.

These beds consist of great sheets of augitic and felspathic lavas, with intervening beds of ashes, lapillæ, pisolitic iron ore (in Antrim), and lignite beds with plants, the examination of which enabled the late Professor Edward Forbes to determine the Miocene age of these rocks. These volcanic sheets rest generally on a floor of chalk, or of some older formation, and all observers are agreed that they have been poured out upon a land surface. It is probable that, at one or more intervals, lakes were formed, and the valuable pisolitic iron ore of Antrim may be referred to this mode of origin.

These volcanic products have undergone enormous denudation since the Miocene period, and on the little map Figure 2, Plate XXXIII., I have endeavoured to show the original area overspread by them.

* Quart. Journ. Geol. Soc., 1880.

† This interval is partly represented by the Maestricht beds of Belgium.

Plates XXXIV. and XXXV.

The Glacial, or Post Pliocene Period.

The Glacial or Post Pliocene period has been generally, and, as I believe, correctly, distributed into three distinct epochs, which merge into each other but were each of prolonged duration. During each epoch the climatic conditions, the relations of land and sea, and the resulting deposits, were different, and may be briefly tabulated as follows for the area of the British Isles.

The Glacial Period.

Epoch or Stage.	Terrestrial Conditions.	Climatic Conditions.	Formations.
3. Upper,	Partial submergence,	Sub-arctic,	Upper Boulder Clay.
2. Middle,	Deepest submergence,	Temperate,	Middle Sand and Gravel.
1. Lower,	Greatest elevation of land,	Arctic,	Lower Boulder Clay or Till.

Between these deposits and the Norwich crag are some interesting Glacial or sub-Glacial beds, indicating the approach of the Arctic conditions which prevailed during the formation of the Lower Boulder Clay.*

Plate XXXIV. represents the physical conditions of the British area during the Lower Glacial stage, represented by the Lower Boulder Clay (epoch or stage 1), and the general glaciations of the exposed rock surfaces. It will be observed, that the whole of the present area of the German Ocean, as far south as lat. 51° 30′, was filled with a great ice-sheet, stretching southwards from the Scandinavian peninsula,† which, at that epoch was covered, like Greenland at the present day, with a continuous sheet of snow and ice. This ice-sheet became divided into two divergent sheets in lat. 57° 30′ owing to the obstruction to its course caused by the position of the Scottish Highlands and the large masses of ice descending in an easterly direction from the snowfields of the Grampians. While one portion took a south-westerly course towards the Norfolk Coast, another moved in a direction perpendicular to this, and passing over the Orkneys,‡ and the northern end of Caithness in an N. W. direction,§ protruded outwards into the Atlantic.‖ The Scandinavian ice-sheet, however, does not appear to have extended to the Faröe islands, which, as Dr. J. Geikie has recently shown, were glaciated by ice, having a strictly local origin amongst the central heights of these islands them-

* These deposits are included in Mr. J. S. Wood's "Lower" and "Middle" Glacial series ; but as Dr. J. Geikie has shown, they are of older date than the three stages given above.—"Great Ice Age," p. 370 (1874.)

† Croll, "Climate and Time" p. 444.

‡ Peach and Horne, Quart. Journ. Geol. Soc. vol. xxxvi., p. 648.

§ T. F. Jamieson, *Ibid.*, vol. xxii. p. 261.

‖ Dr. Croll, *Ibid.*, Map. p. 449. Mr. Croll takes the margin of the ice-sheet much further westward in the Atlantic than that shown in Plate XXXIV. It would be impossible to determine the true limits, which in all cases must be hypothetical.

selves.* This great Scandinavian ice-sheet was joined by another descending from the snowfields of the northern highlands, which passed right across the Minch and over the lower parts of the Outer Hebrides into the Atlantic. Large masses of ice descended in a southerly and westerly direction from the mountains of Perthshire and Argyleshire, as indicated by the glacial striæ of the rock surfaces, and uniting with that of the southern uplands of Scotland,† passed westwards across Cantyre and the North Channel. From the western and northern coast of Ireland, the ice likewise protruded seaward, so as to form with that of Scotland a nearly continuous sheet, as indicated by the arrows.‡ The whole of Ireland was covered by an ice-sheet, moving from an axis which stretched from the neighbourhood of Lough Corrib, in the S. W., to Lough Neagh, in the N. E.§ This mass was augmented by others of smaller size and extent, descending from the local snowfields of Donegal, Galway and Mayo, Cork and Kerry, Waterford and Wicklow. The whole of the Irish Sea, as far south as lat. 52,° was probably filled with ice, coming from Ireland on the one hand, and from the south of Scotland, and the north of England on the other. The ice moved across Anglesea in a S.S.W. direction,|| and along, and over, parts of the Isle of Man in a nearly parallel course.¶ The course of the ice-path in Lancashire and Cheshire is indicated by the arrows.** The glaciers of North Wales were not of sufficient magnitude to deflect the northern ice from its course, but only augmented its volume. Along the banks of the Mersey, at Liverpool, the direction of the ice-flow was S. 35°, E.†† The exact southern limit of the ice-sheet across England is not certain, but it is probable that it ranged across somewhere south of Welshpool, Shrewsbury, and Birmingham. In the centre of England the northern ice-sheet came in contact with that from Scandinavia, the former presence of the latter being indicated by the chalky Boulder Clay.‡‡ It is probable the high district of the Carboniferous Limestone and Millstone Grit of Derbyshire and Lancashire was not overflowed by the ice; the same observation applies, with less of certainty to the ridge of the Cleveland Hills, and of the Chalk, north of the Wash; west of this ridge the red Boulder Clay of the northern ice-sheet is distributed. The direction of the ice movement along the north-east of England has been noted by Sir A. Ramsay,§§ and that of the

* Trans. Roy. Soc. Edin., vol. xxx., p. 217.

† J. Geikie, "Great Ice Age," Plate xv. and text.

‡ Rev. M. Close, Journ. Roy. Geol. Soc. Ireland, vol. i.

§ "Phys. Geol. and Geog. of Ireland," p. 225, and map, p. 211.

|| Sir A. Ramsay, "Phys. Geog. of Great Britain," 4th edt., p. 403.

¶ Rev. J. Cumming.

** R. H. Tiddeman, Quart. Journ. Geol. Soc., vol. xxviii. 490; and J. G. Goodchild, *Ibid.*, vol. xxxi. p. 55.

†† G. H. Morton, Rep. Brit. Assoc. 1870.

‡‡ S. V. Wood, Quart. Journ. Geol. Soc., vols. xxiii. and xxxvi.

§§ *Supra cit.*

valley of the Forth, by Professor Geikie* and his brother. The sheets of ice descending from the Grampians were met by those descending from the snowfields of the southern uplands, and both united took an eastward course till being opposed by the heavy masses of Scandinavian ice blocking the north sea, the stream was deflected southwards and passed along the north-east coast of England. The extreme southerly margin of the ice was limited by its melting, and doubtless numerous muddy streams issued forth at its base, while the Atlantic was filled by large bergs breaking off at the ice-foot and floating southwards with the oceanic current, as in the Greenland sea at the present day.

Mr. W. Keeping has recently given valuable information regarding the Glacial deposits of Central Wales.†

In the south-east of England, the Lower Boulder Clay of Lancashire was preceded by beds of gravel and clay with erratics, constituting Mr. J. S. Wood's "Middle" and "Lower Glacial" series, and by which the great Chalky Boulder Clay, the true representative of the Lower Boulder Clay of Lancashire, is separated from the Norwich Crag.‡

Elevation of Land.—There is reason to believe that during this early stage of the Glacial period the land was elevated, and that much of the shallower portions of the sea-bed were laid dry. Under these circumstances the South of England would have been united to France (as shown in Plate XXXIV.), while the north sea would have been shallow. But, as Dr. Croll believes, the mass of ice from Scandinavia was so great that it took possession of the north sea, dislodging the waters which were insufficient in depth to break it up, and float it away in the form of bergs.

As regards our knowledge of the direction of the ice-flow, the evidence is mainly of two kinds, that derived from the lines and groovings found on rock-surfaces *in situ;* and that derived from the nature of the Boulder Clay, or Till, and the stones or boulders it contains. It being assumed that this deposit has been formed by the ice-sheet, the stones which it contains can often be traced to their sources, and thus the direction of the ice movement becomes known.§

On the other hand, erratic blocks strewn over the surface are not to be relied upon as evidence of the former presence of an ice-sheet, as in many cases they have been carried by floating ice from their original sources at a time when the country was partially submerged. The periods of submergence follow that of the great ice-sheet, and are illustrated in the succeeding maps, in Plate XXXV.

* Geological Map of Scotland, "The Great Ice Age," &c.

† Geol. Mag., No. 216 (June, 1882).

‡ I agree with Dr. J. Geikie in considering Mr. Wood's Cromer Series as preceding the Lower Boulder Clay of the West of England, and as representing probably the true Till, with fresh-water beds lying at the base of the Glacial Series of Scotland.

§ Mr. D. Mackintosh has ably carried out observations of this kind.

Plate XXXV. Fig. 1.

Interglacial Epoch.

The Interglacial, or second, epoch of the Post-Pliocene period presents a remarkable contrast with that which preceded it. Instead of intense cold, there was a temperate climate similar to our own; instead of elevation of the land, there was deep depression and extensive submersion beneath the waters of the sea; and instead of the formation of a glacial deposit like the boulder clay, there was the deposition of beds of sand, gravel, and loam, often containing sea-shells identical with existing species. The physical conditions of the two epochs could scarcely have been more different over the area here described, but this difference was by no means confined to the limited region of the British Isles. It extended, as Dr. Oswald Heer has shown, to Switzerland and the centre of Europe, and as Dr. Dawson has shown, to North America.

The occurrence of an interglacial stage between two others of a glacial character, is admitted by most writers on the physical history of Post-Tertiary times.* The representative beds, or formations, have been recognised both in the west and east of England; but some observers, including Dr. J. Geikie and Mr. S. V. Wood, consider these threefold stages not to be representative of each other in time, but to some extent consecutive. This is a view which, upon careful consideration of the subject, I am satisfied is based upon good grounds. In the east of England, the consecutive deposits in succession to the Norwich Crag are so clearly and fully represented, that they enable us to trace the successive stages of the earlier glacial epoch, in a manner of which we have no where else a parallel. Agreeing with Dr. J. Geikie, that there are beds in Norfolk intermediate between the beds of the glacial epoch and the crag, not represented in the West of England, the following appears to be the succession, as made out by Messrs. S. V. Wood and Rome, with their western equivalents.

Representative Post-Pliocene Series.

Lancashire, Cheshire, &c.	East Anglia.
Upper Boulder Clay, ...	Hessle Clay with Boulders.
Middle Sands and Gravels (marine), . .	Marine Gravels, giving place to littoral and fresh-water Gravels.
Lower Boulder Clay.	Purple Boulder Clay of Yorkshire. Do. with Chalk. Great Chalky Boulder Clay.

* Dr. James Geikie, "Great Ice Age," 2nd edit., p. 328. Sir C. Lyell, "Antiquity of Man," 4th edit., p. 259–60. Dr. Geikie and Dr. Croll consider there were several interglacial stages; but however this may have been in Scotland, only one can be recognised in England and Ireland with certainty. The more mountainous character and higher latitude of Scotland may account for many of the peculiarities of its glacial history. The changes from one set of conditions to another was doubtless gradual and slow.

Representative Post-pliocene Series—continued.

Lancashire, Cheshire, &c.	East Anglia.
Earliest Glacial Beds represented in the north of England and Scotland by the "True Till," with Fresh-water Beds, ...	Sand and rolled gravel with shells.* Contorted Drift with masses of Marl and Chalk. Boulder Clay with Erratics.† Laminated Blue Clay. Fluvia-marine Sand and Clay.
Pre-glacial Beds, ...	2. "Forest bed of Cromer." 1. Sand and Gravel with Loam (Norwich Crag). Chalk.

Taking a general view of the subject, it must be supposed that the glacial and sub-glacial beds overlying the forest bed of Cromer were the precursors of the great land ice-sheet, represented by the Great Chalky Boulder Clay, and that the marine gravels overlying the Purple Boulder Clay are the representatives of the middle sand and gravels of Cheshire, Lancashire, Wales, Wicklow, and Wexford.‡

The beds formed during the interglacial stage above described are widely distributed, consising of sand, gravel of water-worn pebbles, and beds of loam, generally finely laminated; they give evidence of deposition under water. The occurrence of sea shells in various parts of the British Isles, proves that this water was the sea, and the genera and species vary somewhat according as warm or cold currents were present. Sometimes the gravels are found resting directly on the Lower Boulder Clay, as at Howth and Killiney, in Ireland, on the banks of the Ribble, near Preston, and in East Anglia. In other places they rest directly on the solid floor of the older rocks. They also cover large tracts of the central plain of Ireland, ascend on the Wicklow mountains to an elevation of 1,235 feet, as shown by the Rev. Maxwell Close, and occur along the eastern coast of Ireland, often overlaid by the Upper Boulder Clay. Amongst the Sperrin mountains in Ulster they have been found by Mr. Joseph Nolan at an elevation of 1,200 feet. Amongst the mountains of North Wales they have been detected by the late Mr. J. Trimmer,§ by Mr. D. Mackintosh and others at somewhat higher elevations, and by Professor Prestwich on the hills near Macclesfield, at an elevation of about 1,100 to 1,200 feet.|| They are spread over large tracts of Lancashire, Cheshire, and Salop, sometimes occurring at the surface, but as often concealed beneath the Upper Boulder Clay. In the central counties they are extensively distributed, and on the tableland of the Cotteswold Hills of Gloucestershire and Oxfordshire, I have traced them to

* Mr. Woods' "Middle Glacial Beds."

† Mr. Woods' "Lower Glacial Beds."

‡ The presence of *Fusus contrarius*, and two or three other forms supposed to have been extinct, but represented in the Suffolk Crag, induced the late Professor Edward Forbes to refer the Wexford gravels to the age of the Crag, but this shell has recently been dredged up off the coast of Spain as a "living" form. Professor Haddon has shown me a specimen from the collection of the Royal College of Science, Dublin.

§ On Moel Tryfaen at 1,360 feet. The shells have subsequently been named by Mr. R. D. Darbyshire.

|| Lyell, *Ibid.* p. 317.

elevations of about 600 feet.* The "high-level" gravels of Berks, Wilts, Dorset, and Oxfordshire are also probably referable to this division of the drift series. Representative beds are also present in the east of England, interposed between two boulder clays. In the west of Scotland I have found similar beds of gravel and sand high up amongst the hills of Cantyre, and at less elevations in the neighbourhood of Glasgow. Out of these gravel beds the more recent Eskers or Kames appear to have been constructed. The south of England was probably only very slightly submerged at this stage.

Such then is a general account of the distribution of these interglacial beds. The elevation at which the gravels are found is assumed as an index to the measure of submergence of the land, as they were certainly formed *in situ,* amongst the mountains. This submergence probably reached its maximum of 1,300 or 1,400 feet about the centre of the British Isles, and was less in the south, and perhaps north, of Scotland. At the time the shelly gravels were deposited the British Isles became an archipelago in miniature, and in the little map, plate XXXV., fig. 1, I have endeavoured to represent their condition during the epoch of greatest submergence.†

Plate XXXV. Fig. 2.

The Epoch of the Upper Boulder Clay.

The epoch of greatest submergence, represented in Plate XXXV., Fig. 1, when marine gravels were deposited on mountain slopes of the British Isles at elevations as high as 1,360 feet, and when glacial conditions disappeared, except perhaps amongst the islets formed of the summits of the Scottish Highlands, was succeeded by a second epoch of glacial conditions; not, however, as severe as the first, and one which took place when the lands were partially submerged. After the pause accompanying the deep submergence above referred to, the land began to rise, and considerable tracts of mountainous and hilly ground, previously overflowed by the sea, reappeared, and were converted into dry land. This uprising was accompanied by a return of cold, so that *small* snowfields giving birth to *smaller* glaciers began to accumulate on the higher elevations; and as the glaciers in some cases entered the sea, small bergs and rafts of ice dotted the surface of the water, and carried their freights of boulders, stones, clay and sand in the direction towards which they were impelled by the winds and currents of the period, and as they melted dropped their loads over the submerged tracts. At the same time, owing to the melting of the snow or ice, numerous streams of red, muddy, glacier water entered the sea, which must have been thus discoloured over the central and northern portions of

* Quart. Journ. Geol. Soc., vol. xi., p. 477. Dr. J. Geikie places the submergence in Scotland at not less than 526 feet, or much more. *Ibid.* pp. 163 and 329. Lyell suggests 2,000 feet for Scotland. "Antiquity of Man," p. 324.

† This may be compared with that of Lyell. *Ibid.* p. 325.

the area referred to. From this red mud a deposit would be formed similar to that of the upper boulder clay of Lancashire, Cheshire, North Wales and Ireland, the Hessle clay of Yorkshire,* and its representatives in the north-east of England. This deposit consists of reddish clay, slightly laminated, and containing bands of sand or loam. In some places it contains foreign stones and small boulders brought from a distance, and in a few instances marine shells have been detected in it. Thus at Gorton, near Manchester, the following rock fragments, nearly all foreign to the neighbourhood, were determined some years ago :—†

Silurian grit,	37	per cent.
Felspar porphyry,	31	„
Felstone,	2	„
Carboniferous grit,	14	„
Granite,	6	„
Porphyritic agglomerate,	4	„
Carboniferous limestone,	3	„
Ironstone,	2	„
	99	„

The majority of the above specimens had evidently been transported from the district of Cumberland and North Lancashire, which we may suppose sent off loads of stones and boulders southwards upon ice-bergs and rafts.

The upper boulder clay rises to elevations of 500–600 feet amongst the western slopes of the Lancashire hills, and marine shells (*Turritella terebra, Fusus Bamfius, Purpura lapillus,* &c.) have been found in it; as, for instance, at Hollingworth Reservoir (568 feet above the sea), the vale of Mottram, Bradbury and Hyde.‡ From this elevation it gently slopes southward and westward, towards the plain of Cheshire,§ which is largely overspread by it; it occupies portions of the low valleys of North Wales.|| On the other hand, the Pennine table-land of South Yorkshire and North Derbyshire, and the low country to the east of it are free from drift deposits,¶ a state of things very difficult to explain, but clearly indicating the absence of glacial conditions amongst the eastern valleys of the Pennine chain south of the parallel of 53° 35′ N. lat.

* This is described by Mr. S. J. Wood as a deposit of clay containing a few scattered stones and boulders when the sea extended over the land to an extent not exceeding 350 or 400 feet anywhere in Yorkshire. *Geol. Magazine,* vol. vii.

† By Professor Ramsay and the author. "Geol. of Oldham, &c.," Mem. Geol. Survey (1864).

‡ By Mr. Bateman, C.E., Professor Prestirch, and Mr. John Taylor. "Geol. of Oldham, &c.," Mem. Geol. Survey (1864), p. 51.

§ "Geol. of North Derbyshire." *Ibid,* p. 75.

|| In a pit by the railway side, near Abergele, it may be observed capping the interglacial gravels at an elevation of only 20–30 feet above high water.

¶ "Geol. of Dewsbury, &c.," Mem. Geol. Survey, p. 20 (1871).

In Ireland the upper boulder clay, resting on the marine gravels of the interglacial stage, has been noticed in several places, as at Killiney near Dublin, along the Wexford coast,* at the marble quarries near Kilkenny,† at Modabeagh colliery near Carlow,‡ and in Counties Tyrone, Antrim, and Derry. It is similar to its English representative, but has probably suffered more from denudation, so that it is only to be found in small detached areas. When it was in course of formation the land was in places probably depressed to a level of about 1,000 feet below that it now occupies, and as the sea-bed still further rose, the soft material of which it was composed would have offered but slight resistance to the waves and currents which chafed around the unprotected prominences. In more than one instance which has come under my notice, the formation would seem only to be represented by blocks of travelled stone stranded on the surface. An instance of this kind occurs at Kilkelly, in Co. Mayo, where large slabs of Carboniferous grit are to be found strewn over a tract of country of considerable extent, covered by a thick deposit of gravel on which these blocks are found resting.§

When we turn to Scotland we are met by difficulties of identification, as the geologists of that country do not seem to have recognised a representative to the Upper Boulder Clay.|| Dr. J. Geikie refers to the "Upper Drift Deposits," very diverse materials, such as coarse, earthy débris of angular fragments, and large blocks and boulders which are strewn over the northern slopes of the southern uplands. These he traces to the Grampians as their source, and considers they have been brought to their present position on a second great sheet of ice moving southward.¶ It is, of course possible that the more northerly positions, the greater elevation of the Grampians and North Highland mountains than those of other British districts, and the consequently greater amount of snow and ice which must have accumulated on their summits and slopes, may have produced a second ice sheet which has no representative elsewhere; and in such a case, the central valley, though really below the sea level, and submerged to a depth perhaps of several hundreds of feet, may have been completely filled with ice, which for a time excluded the waters of the sea. But admitting all this, it is inevitable that when the ice began to give way, owing to the approaching amelioration of the climate, it would be

* Professor Harkness, "Geol. Magazine," vol. vi., p. 542.

† "Phys. Geol. Ireland," p. 90. Geikie, "Great Ice Age," 2nd edit.

‡ Hardman, Journ. Roy. Geol. Soc., vol. iv., p. 73; Expl. Mem., Sheet 35 of the Maps Geol. Survey. Here the Upper Boulder Clay was proved to be 84 feet in thickness, resting on 25 feet of sands, gravels, and clays, and this again on Lower Boulder Clay 8 feet. The elevation is about 750 feet.

§ Originally described by Sir R. Griffith, Brit. Assoc. Rep. 1844.

|| My own observations in the Glasgow district, however (1868–9), lead me to think that such a deposit may occur east of that city.

¶ Loc. cit.

broken up into rafts and bergs answering in all respects the description given of the phenomena in England and Ireland.*

The local moraines which existed amongst the higher unsubmerged districts, became centres of dispersion of erratics which were floated to their destination on masses of glacier ice. If (as Dr. Geikie considers) about the time now referred to, the south of Scotland was submerged to the depth of 1,100, or even 1,250 feet,† and the north of England and of Ireland to a depth of about 900 or 1,000 feet, the tract submerged would be very large, and boulders would be carried in directions corresponding to the prevalent winds and currents. The courses travelled by such erratics have been ably traced by, amongst others, Mr. D. Mackintosh, who has traced the boulders over large tracts of country in the north-west and centre of England and Wales to their parent masses.‡ Amongst the more remarkable instances of erratic blocks are those at Pagham and Selsea, mentioned by Lyell.§

It is unnecessary for my present purpose to go more fully into the details of later glacial and post-glacial phenomena. It will probably suffice that I should add that the climaticand geographical conditions of the stage of the Upper Boulder Clay gradually gave place to those which preceded, and ultimately introduced the existing temperate condition of climate. The land gradually rose out of the sea, the rise being probably accompanied by prolonged pauses. The snows and glaciers melted off the mountains. The sea was gradually freed from ice, and the waters became pure and limpid. The plants and animals of the adjoining continent once again flocked over and restored life and verdure to the face of nature. Man, himself, followed in their train, and made his dwelling in the caves of the rocks, living by the chase, and trying his strength with some of the fierce carnivores which infested the forests and dens of the mountains.|| With this state of affairs geology closes its record, and makes way for the researches of the antiquarian and historian.

It will be observed that in the maps referring to the glacial period (Plates XXXIV. and XXXV.) I have represented only the supposed physical restorations of the surface of the country as they were during the three special stages to which they point. I have not attempted to produce corresponding maps showing the distribution of the various glacial deposits. To attempt this would have been impossible on a scale so small as those of these three little maps, even if I had had the necessary materials to guide me. But such is not the case. The mapping of

* Dr. Geikie, and also Mr. Jamieson (Quart. Journ. Geol. Soc., 1865) have treated very fully of the formation of kames (in Ireland called "eskers"), which the former refers to the upper glacial deposits, but I prefer (for reasons I have stated elsewhere, "Phys. Geol. of Ireland," p. 100) to regard them as post-glacial. The phenomena in Ireland are very similar to those of Scotland.

† From Mr. H. M. Skae's observations in Nithsdale.

‡ Quart. Journ. Geol. Soc., London, 1879–82.

§ "Antiquity of Man." p. 280.

|| I place the advent of man as post-glacial deliberately, as Mr. John Evans, F.R.S., our highest authority on such questions, has recently analysed the evidences which have been adduced both in Europe and the British Isles, for assigning to him a pre-glacial advent, and finds them in all cases more or less untrustworthy.

the Quaternary deposits in detail has as yet been very partially carried out by the Government surveyors, or by private agency, and it is of such a character that it could not be effectively reproduced on a single map unless one of a scale not smaller than 10 miles to the inch, or $\frac{1}{6336}$ of nature.*

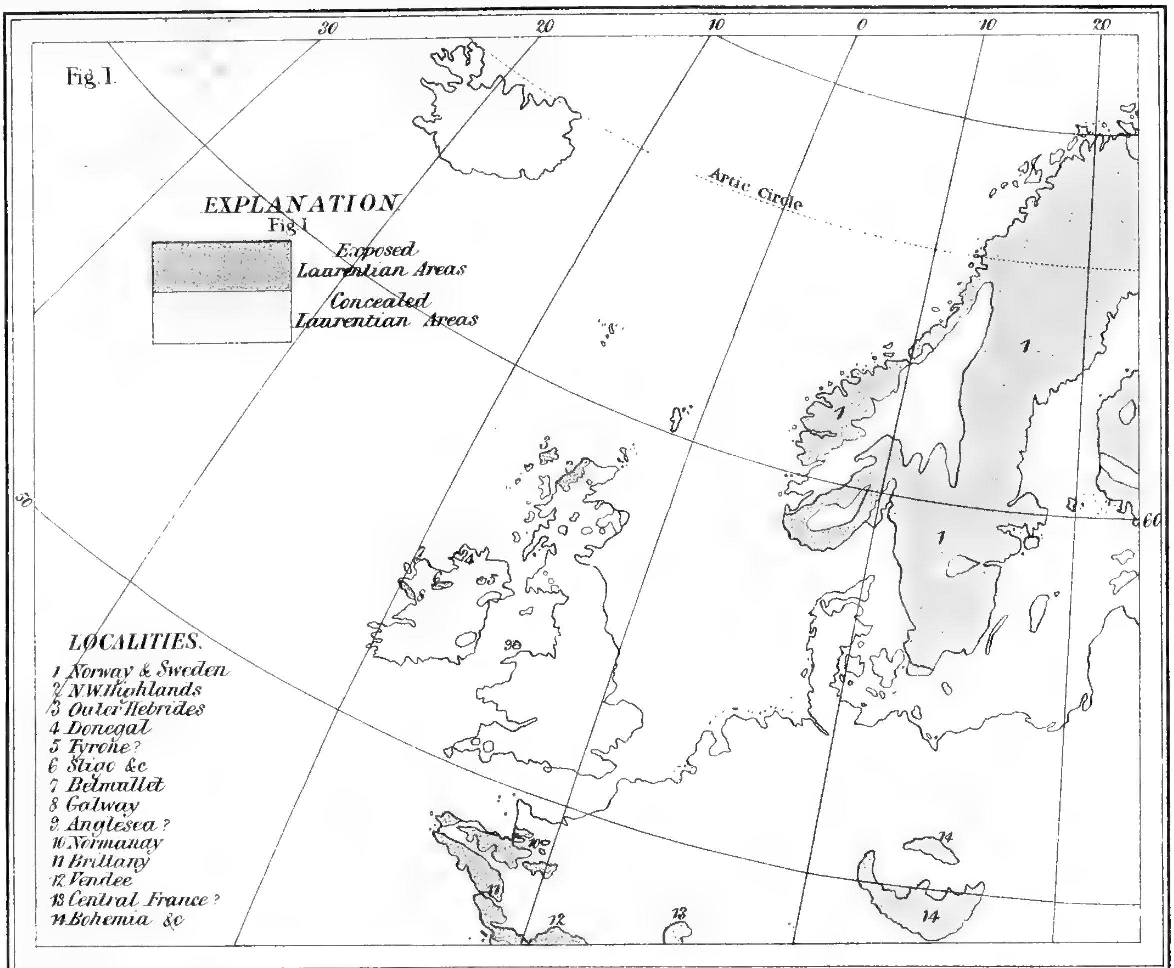
The Upper Boulder Clay referred to above, indicates the recurrence of glacial conditions, but not to the extent of those which prevailed during the formation of the Lower Boulder Clay or Till. In Lancashire and Cheshire this deposit may be seen resting on the interglacial gravels and sands in the banks of the Ribble above Preston, and on the coast near Southport, as well as in many other places. It consists of red clay with stones and small boulders often glaciated, but the clay is laminated, and was evidently formed under water. In the east of England, however, it seems to be represented by a second formation of boulder clay formed by a second protrusion of Scandinavian ice, and known as "the great chalky boulder clay," described by Messrs. Wood and Rome as a "lead-coloured clay abounding in chalk débris accompanied by stones and boulders of all sorts of rocks."† It has been traced from Holderness and the Vale of York and identified with a similar deposit in Norfolk and Suffolk. In Ireland the Upper Boulder Clay has been recognised in numerous places, as at Kilkenny,‡ and other central and northern localities.§

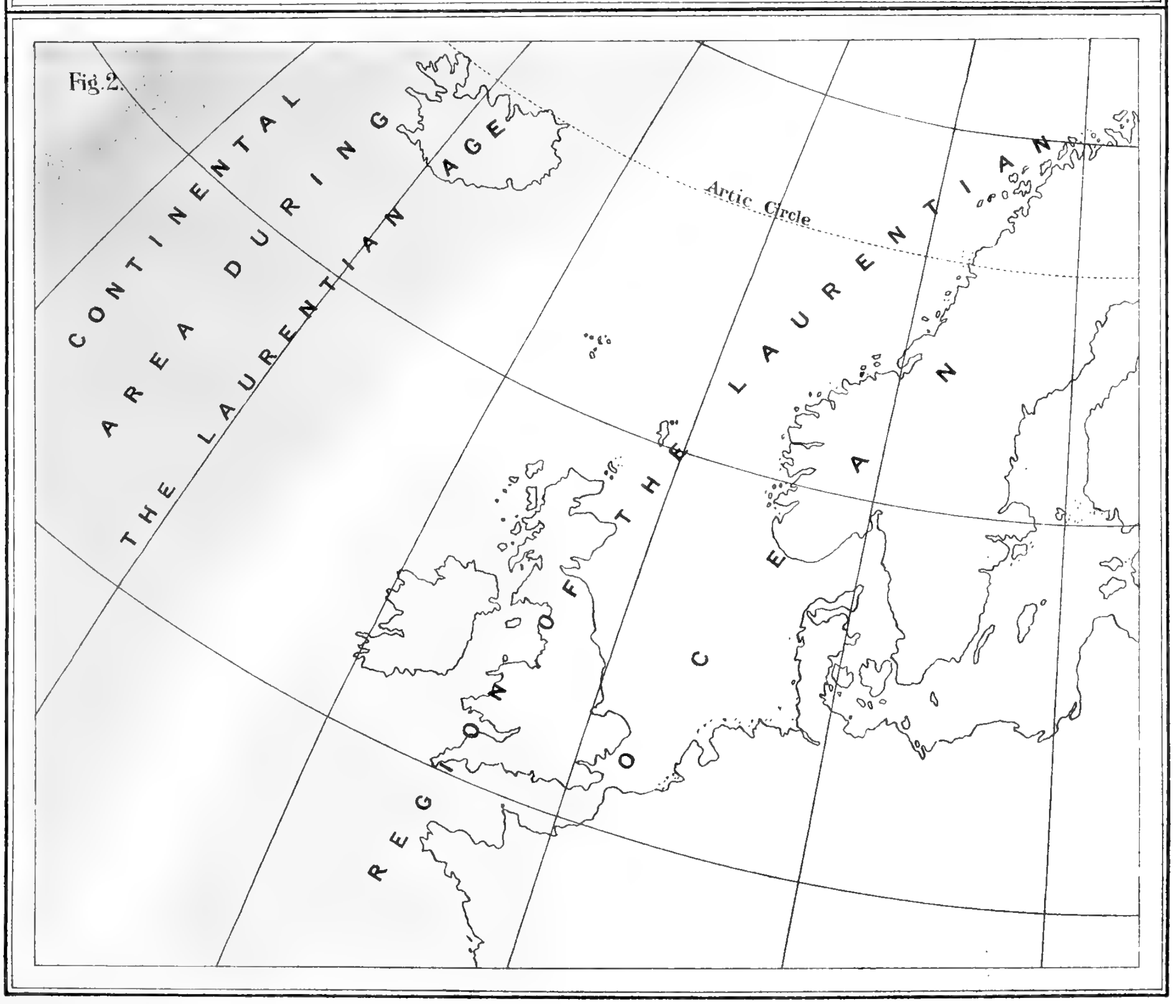
* The minute divisions of the Quaternary series are being carefully laid down on the Government maps of Belgium, "Commission de la Carte Geologique," under the department of the Minister of the Interior, but the scale is a large one, viz. : $\frac{1}{20000}$.

† Quart. Journ. Geol. Soc., vol. xxiv. Mr. S. V. Wood has contributed still more recently another elaborate account of the glacial beds of this part of England.

‡ See woodcut and section ; Geikie, "Great Ice Age," 2nd edit., p. 395–6.

§ Hardman, Journ. Roy. Geol. Soc., Ireland, vol. iv., new ser., p. 73.





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Physical Maps of the Cambrian Period.

Fig. 1.

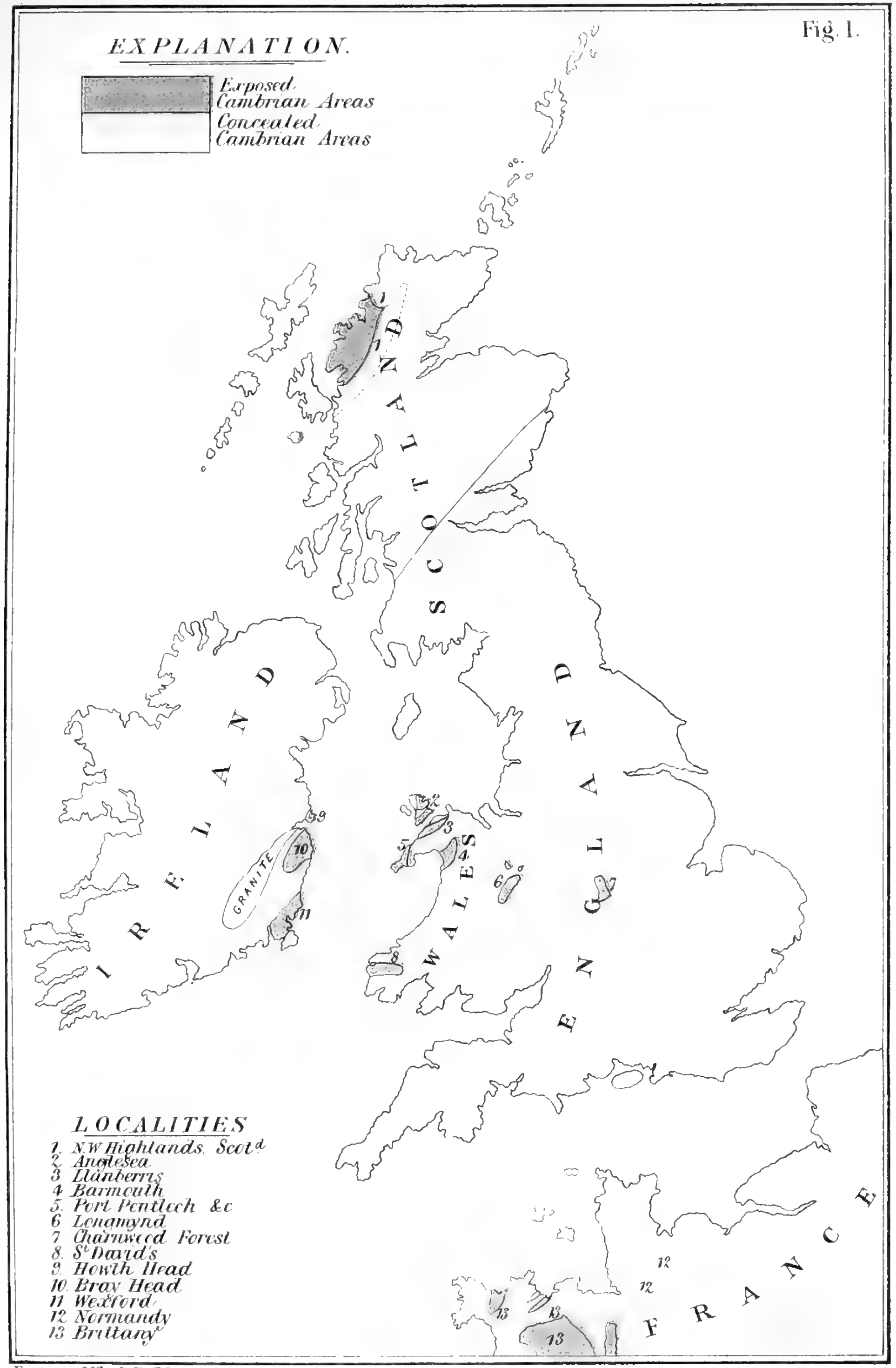
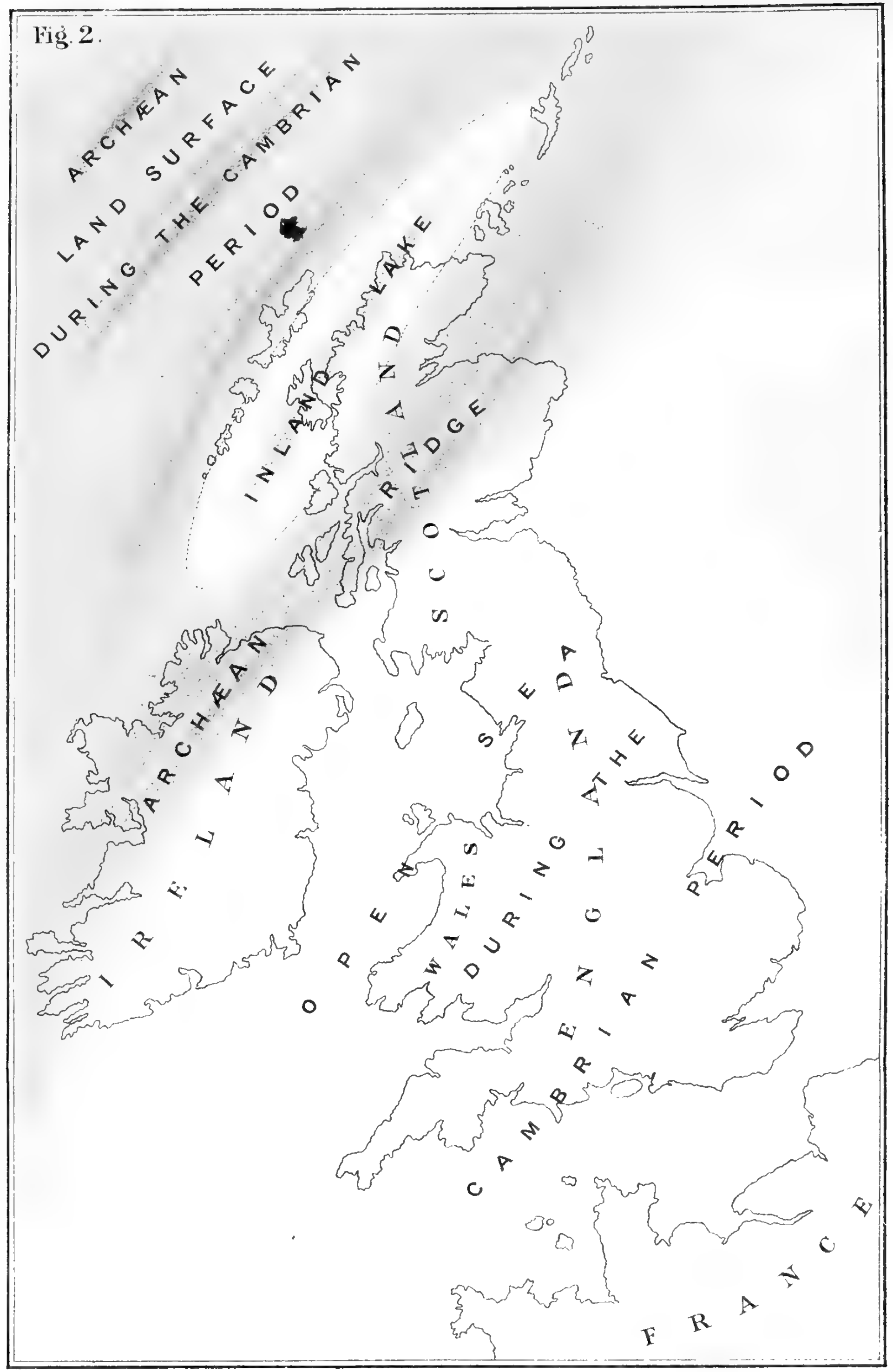


Fig. 2.



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Physical Maps of the Lower Silurian Period.

Fig 1.

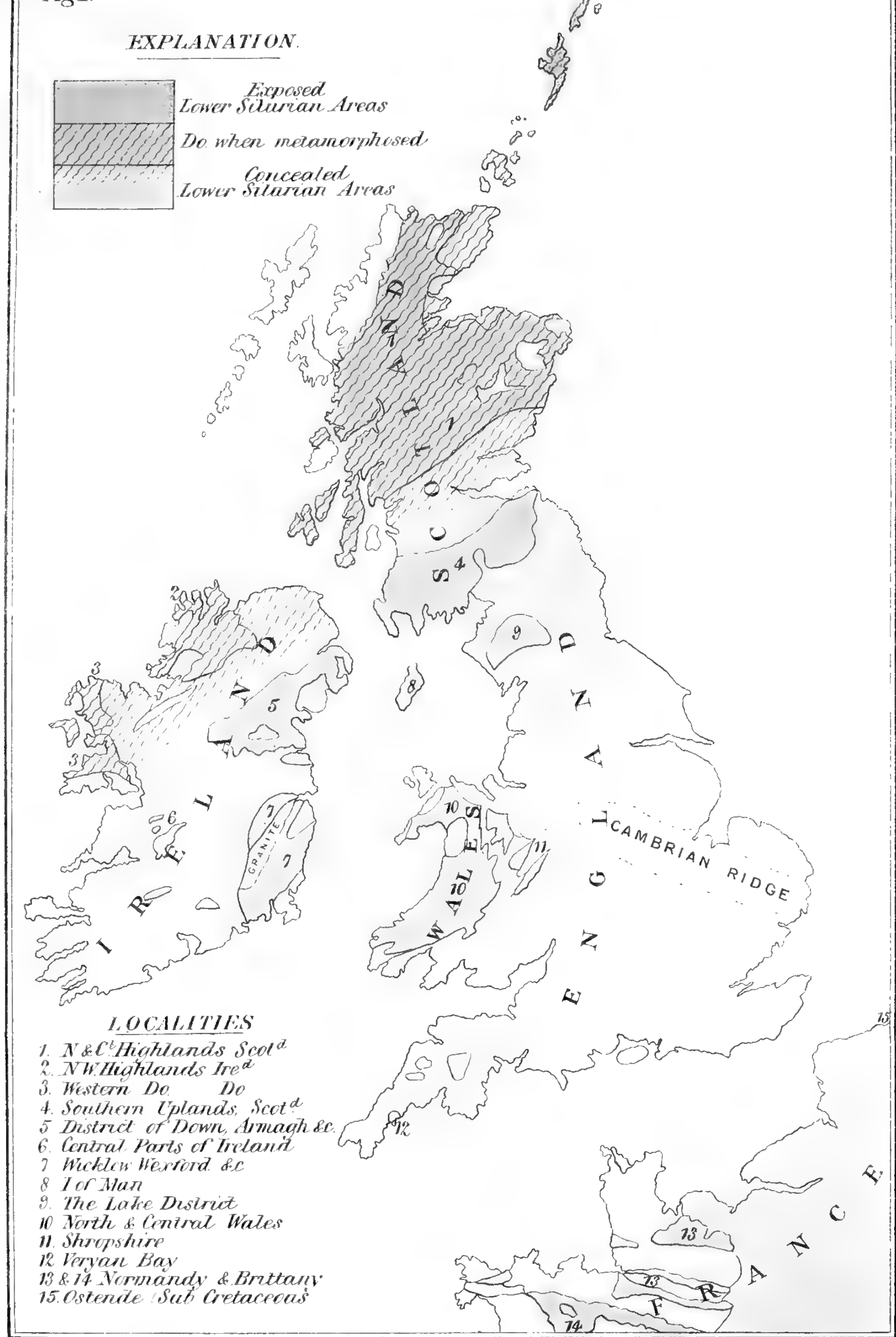
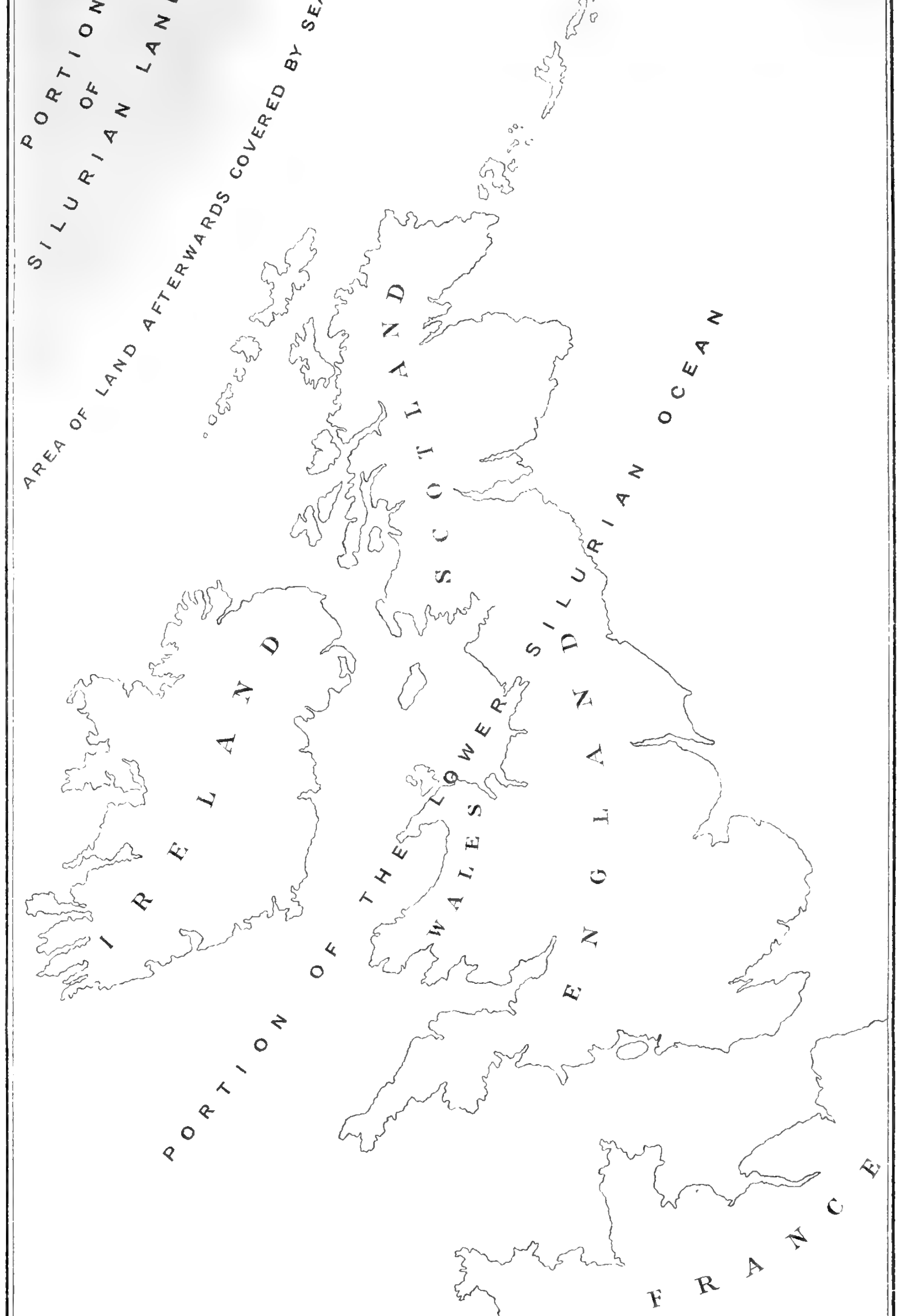
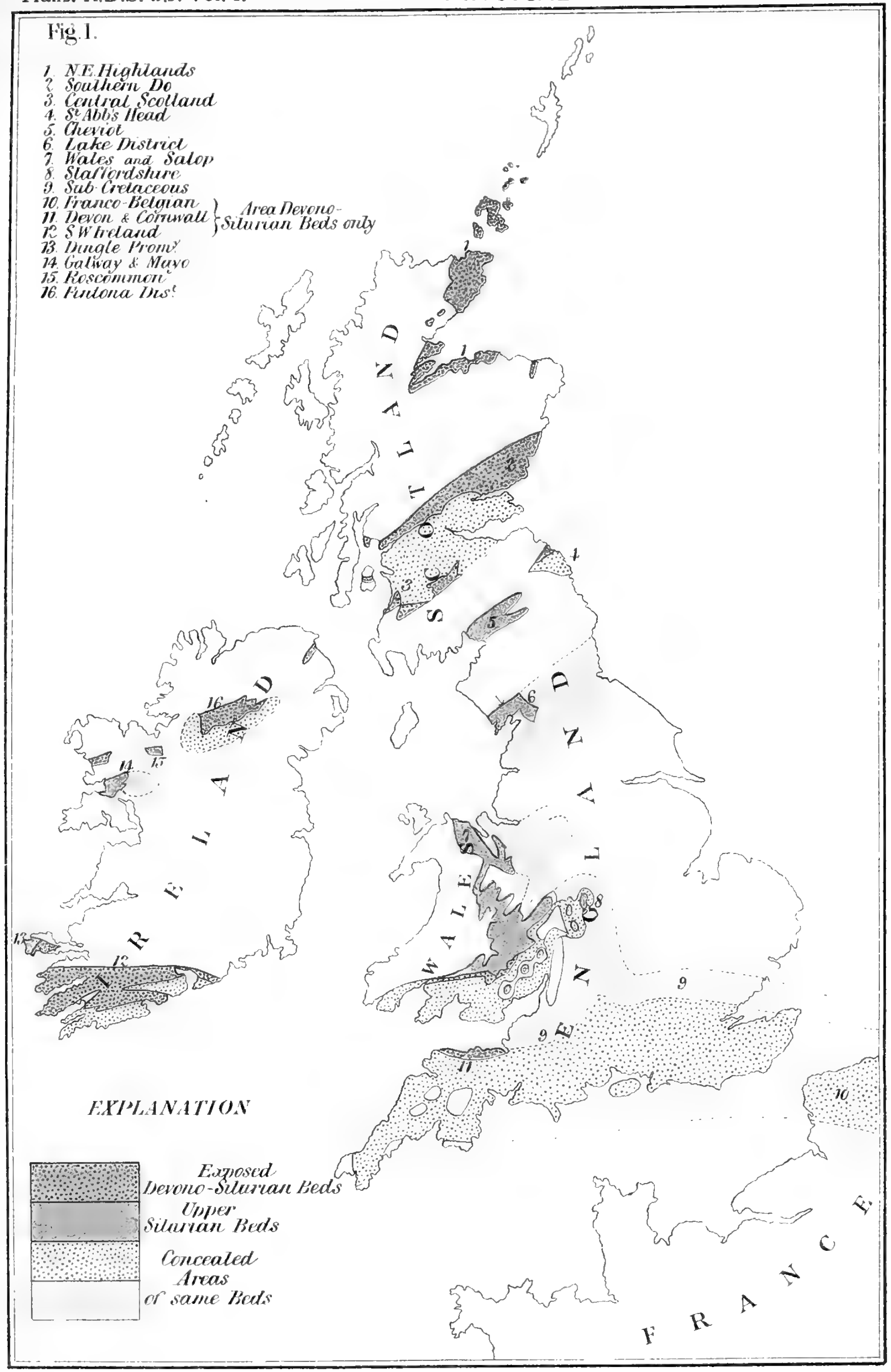


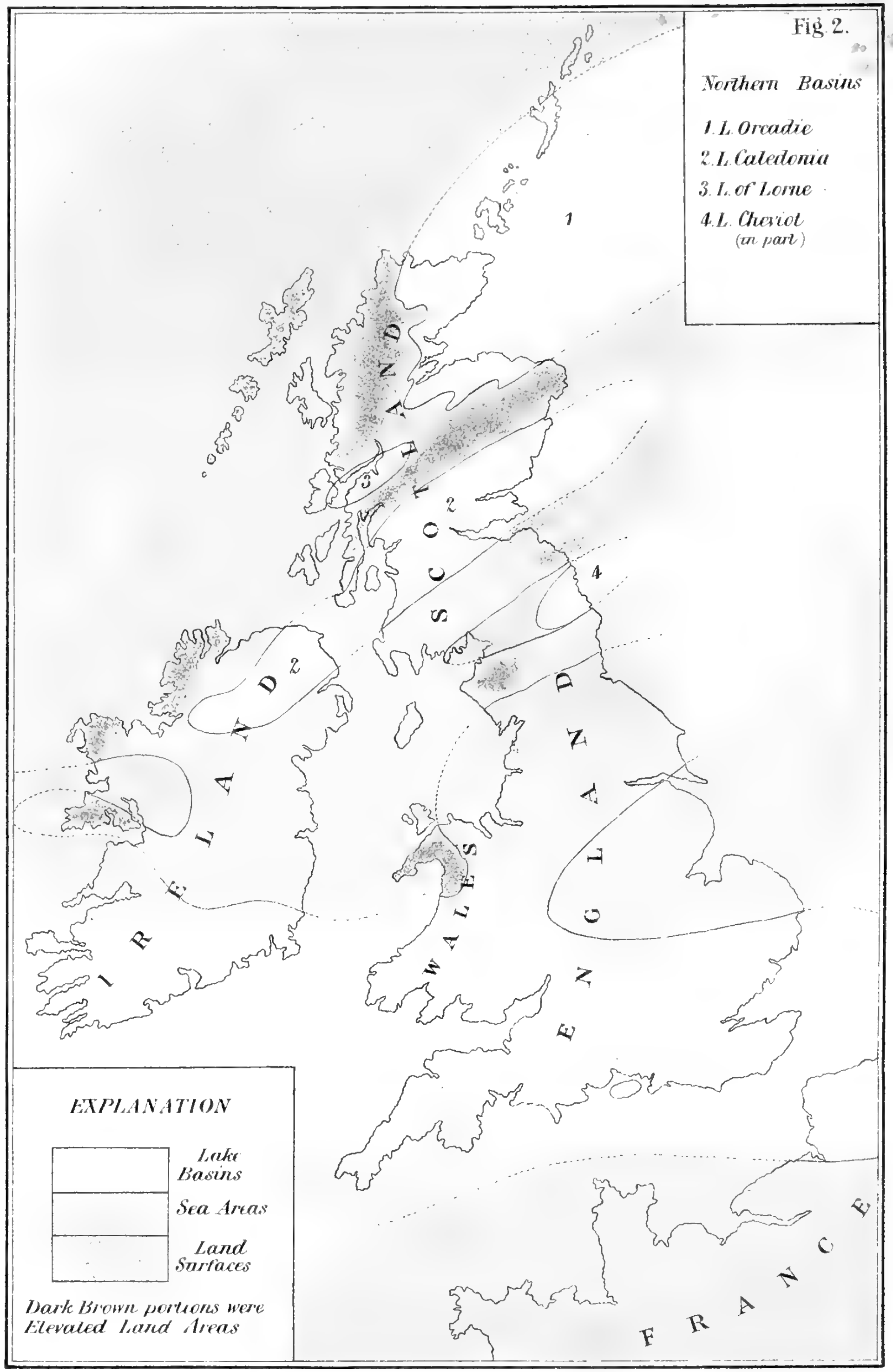
Fig 2.



Forster & Co. Lith. Dublin

Physical Maps of the Upper Silurian and Devono-Silurian Periods.





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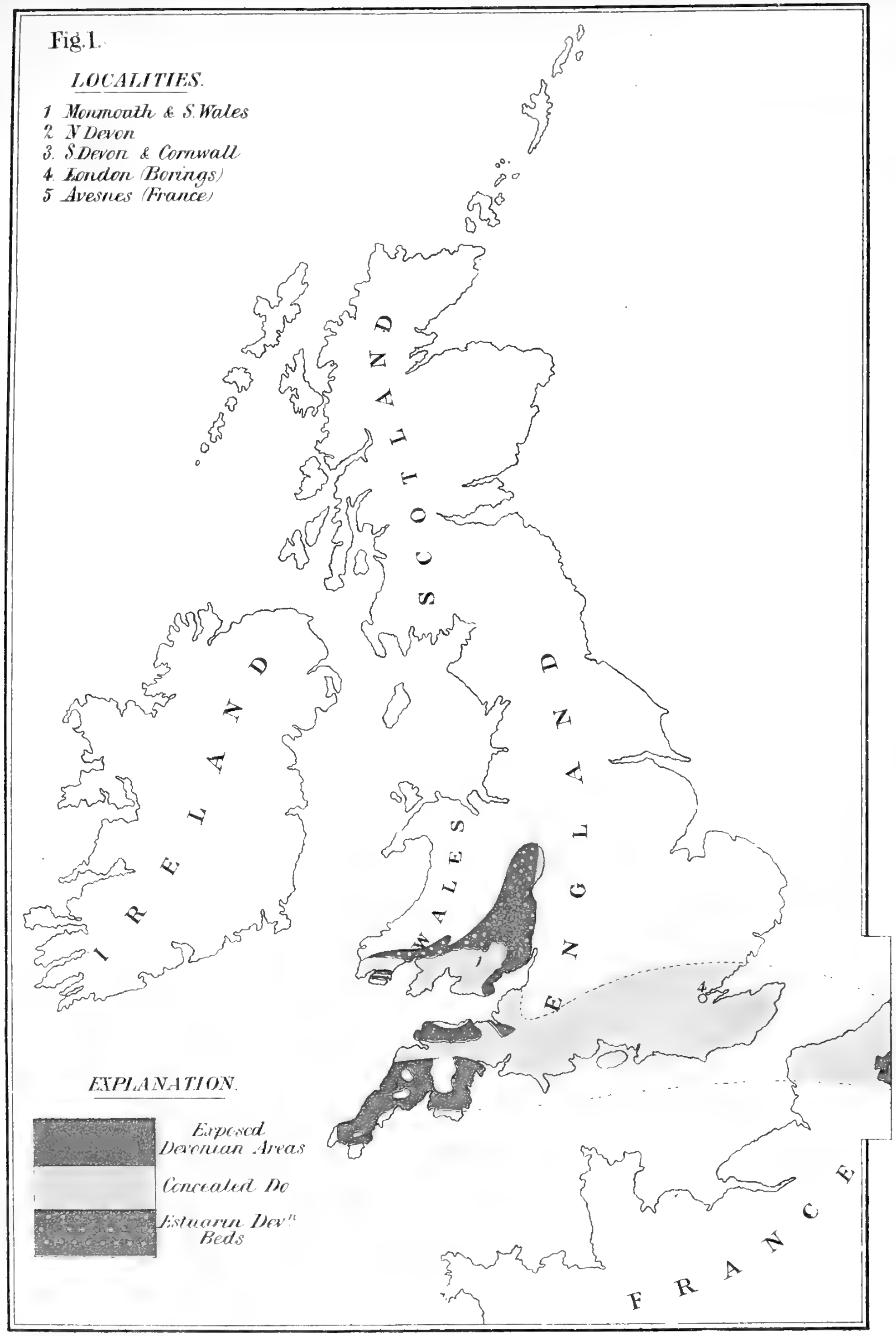
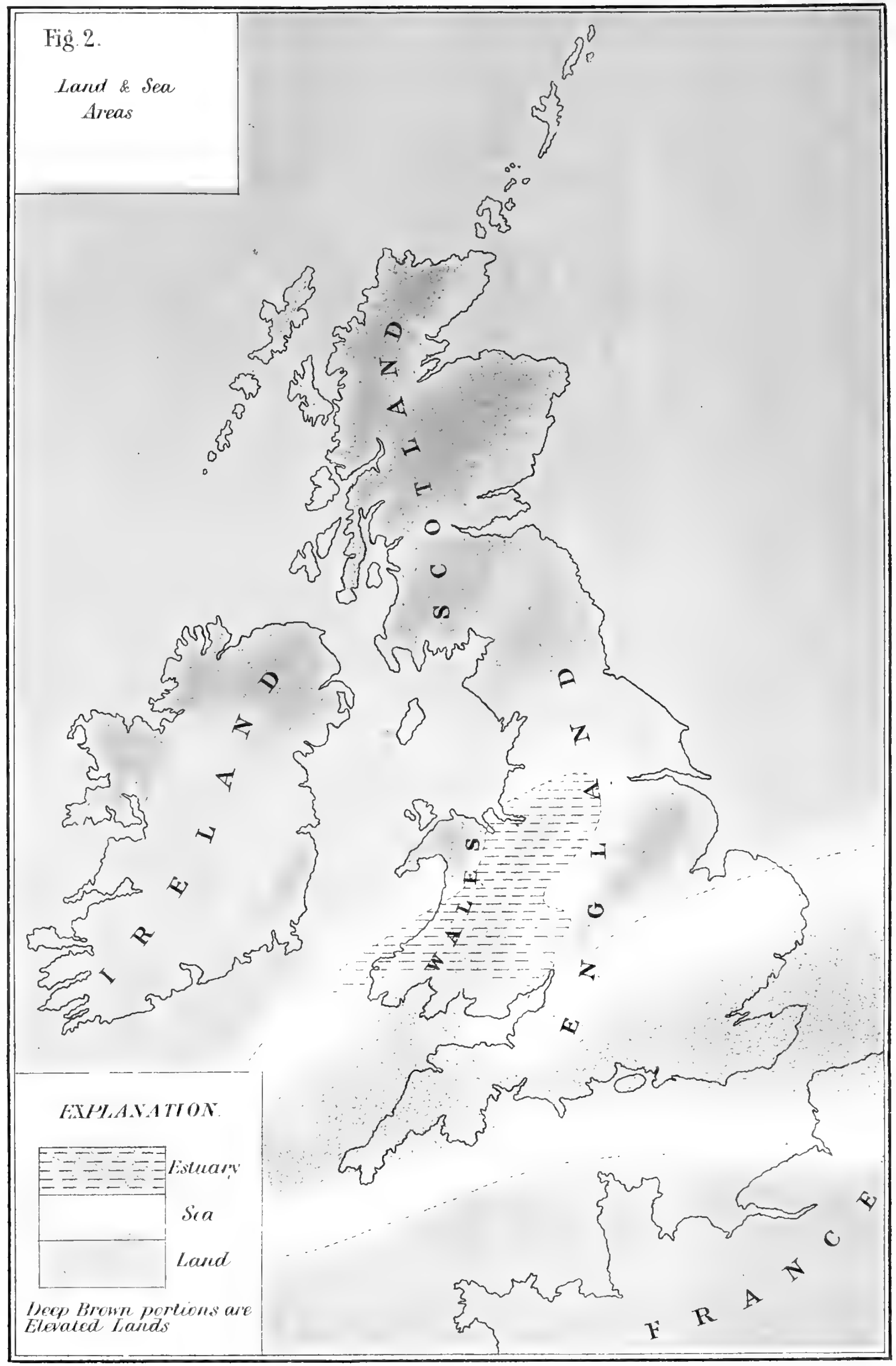
PHYSICAL MAPS OF THE LOWER AND MIDDLE DEVONIAN PERIODS.





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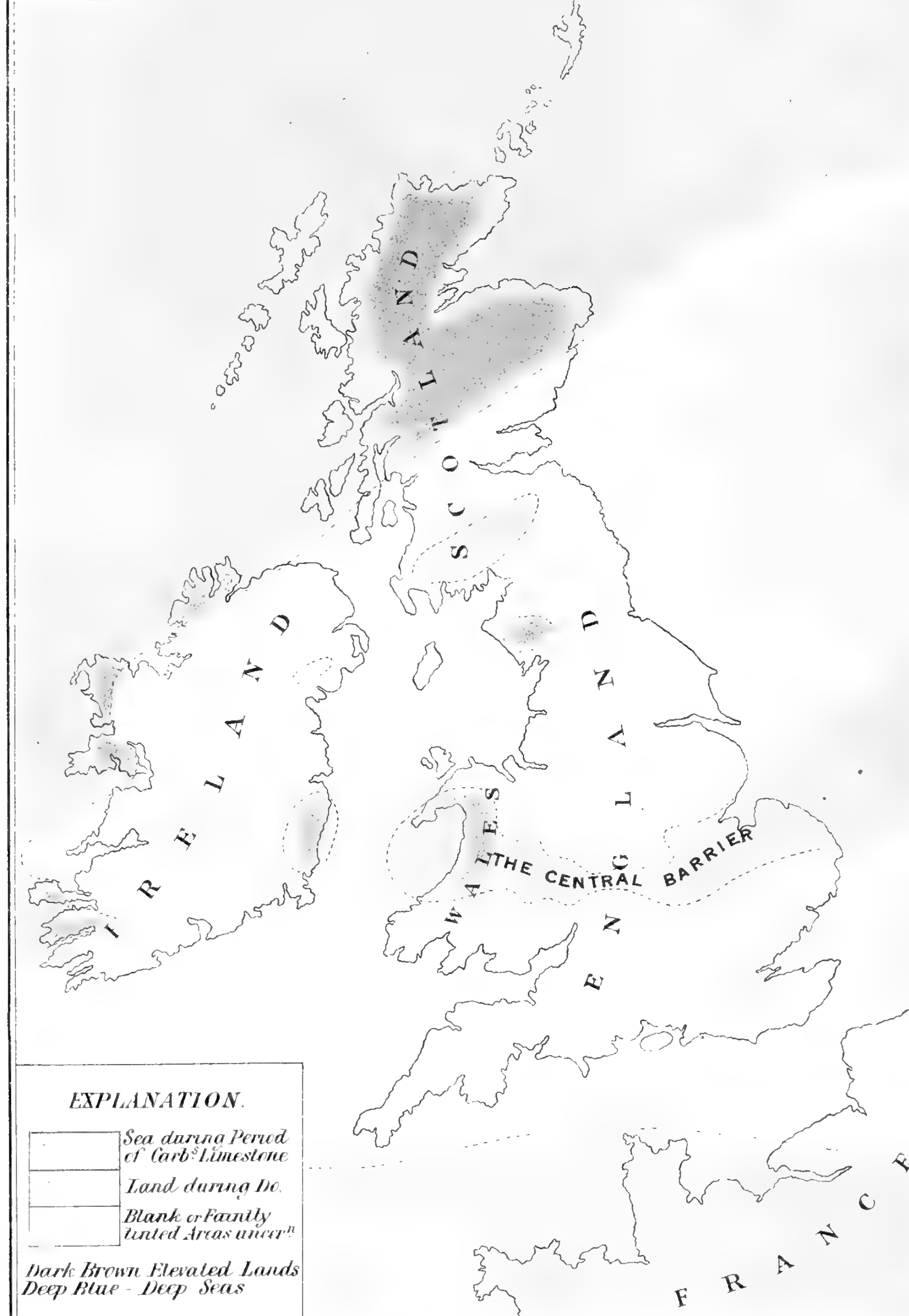
Physical Maps of the Old Red Sandstone and Lower Carboniferous Periods.

Fig. 1.

Fig. 2.



Forster & C^o Lith Dublin

PHYSICAL MAPS OF THE UPPER CARBONIFEROUS PERIOD.

Fig. 1.

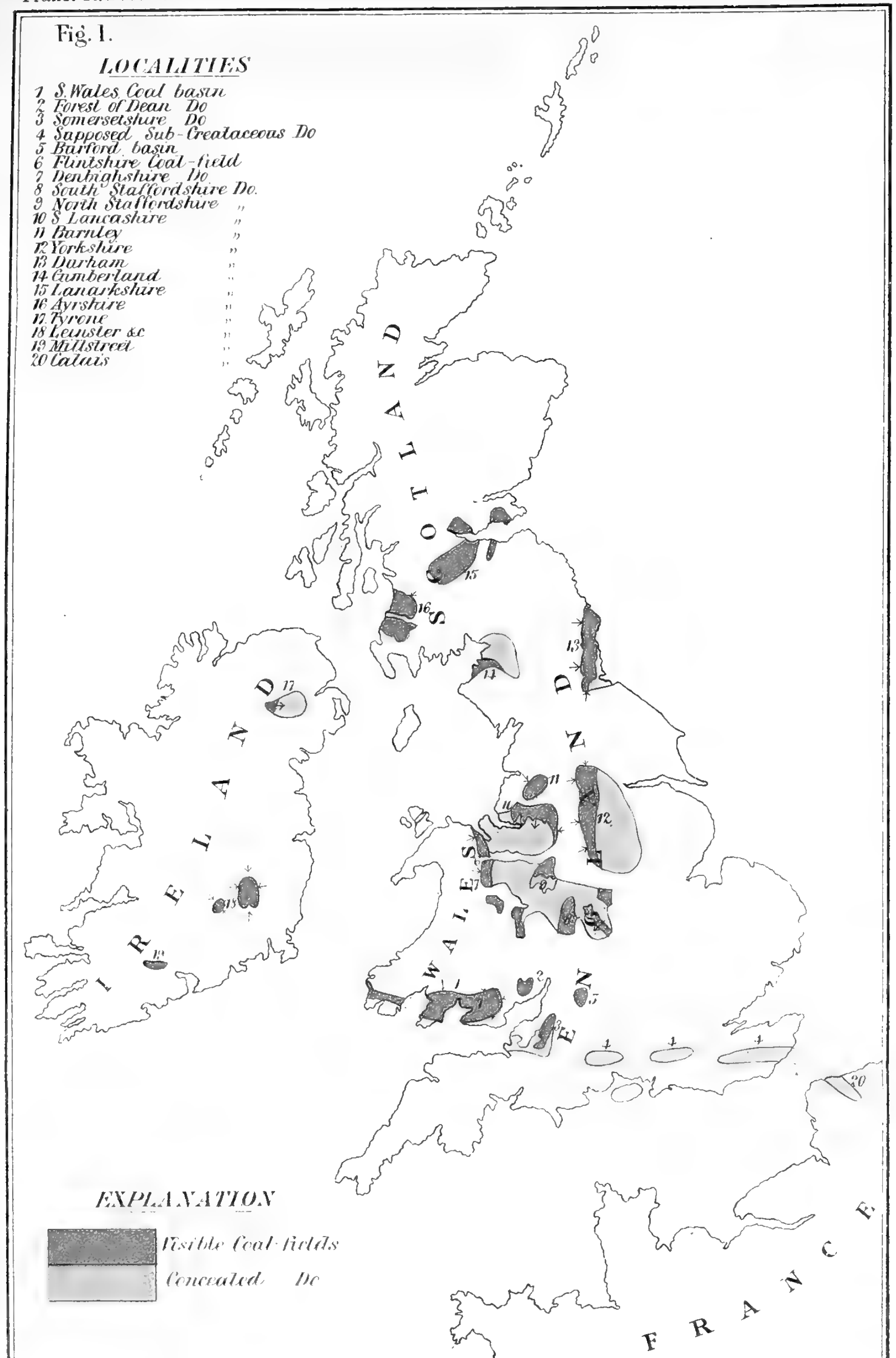
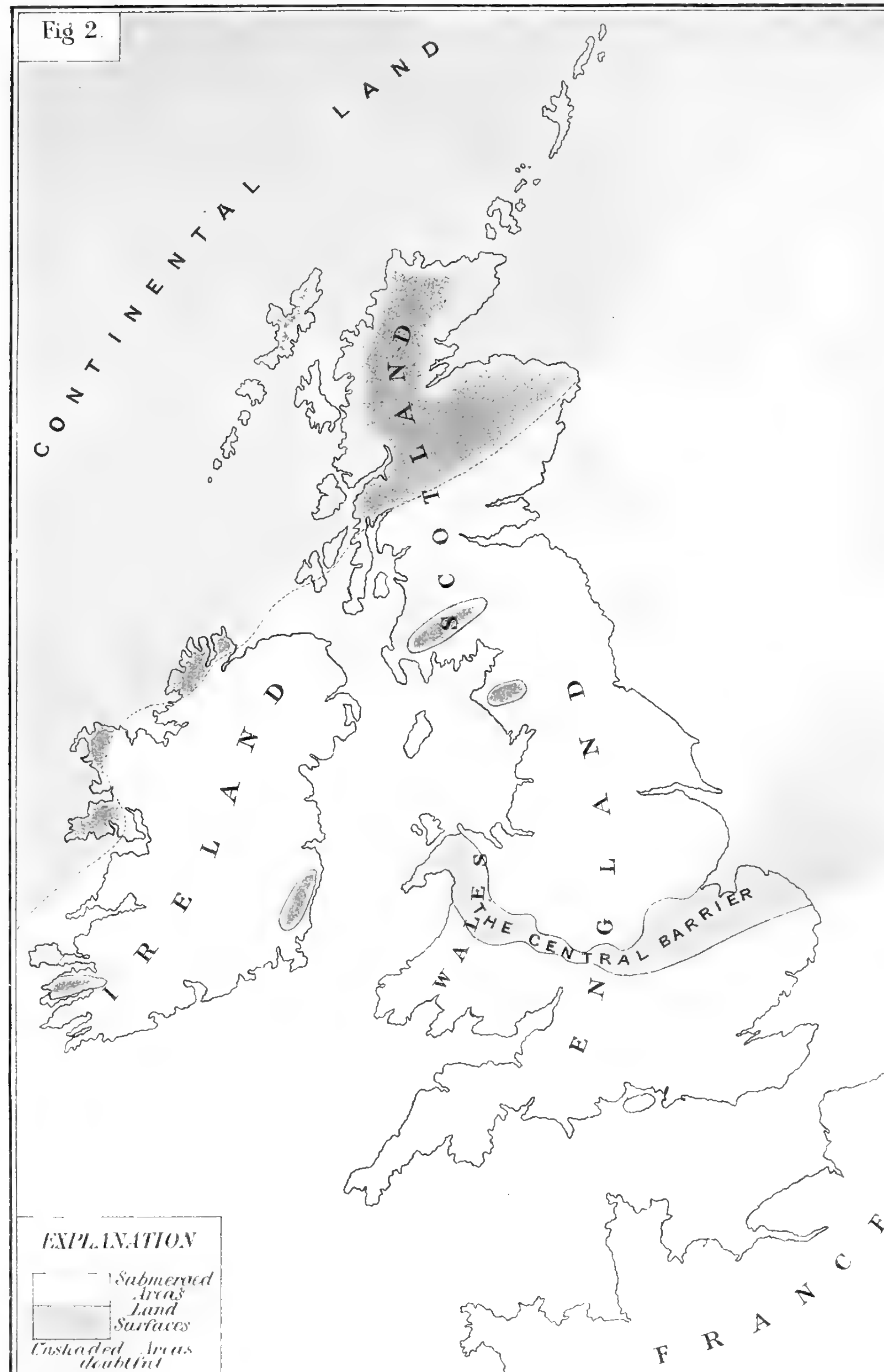


Fig 2.



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Physical Maps of the Permian Period.

Fig. 1.

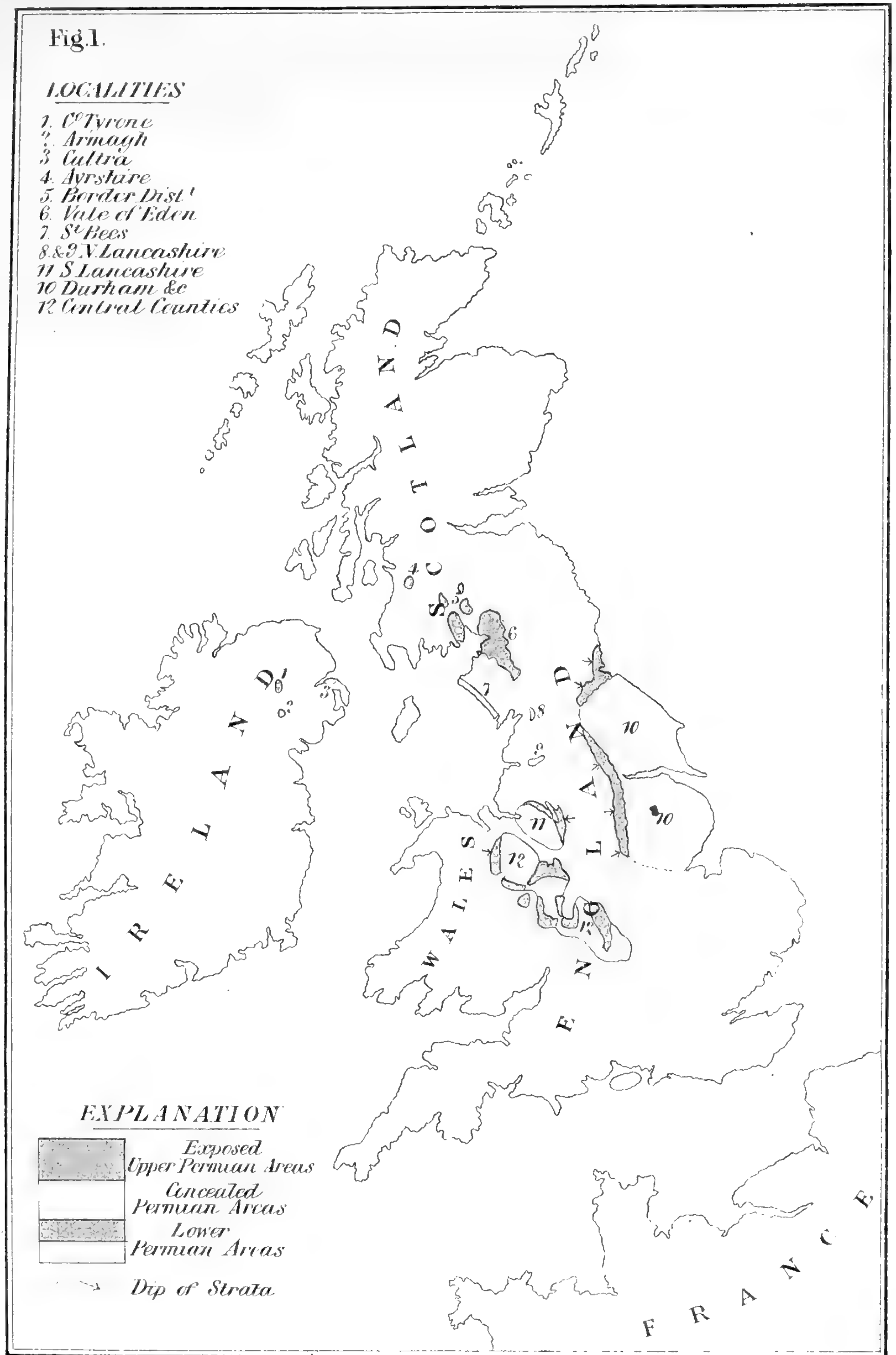

Fig. 2.

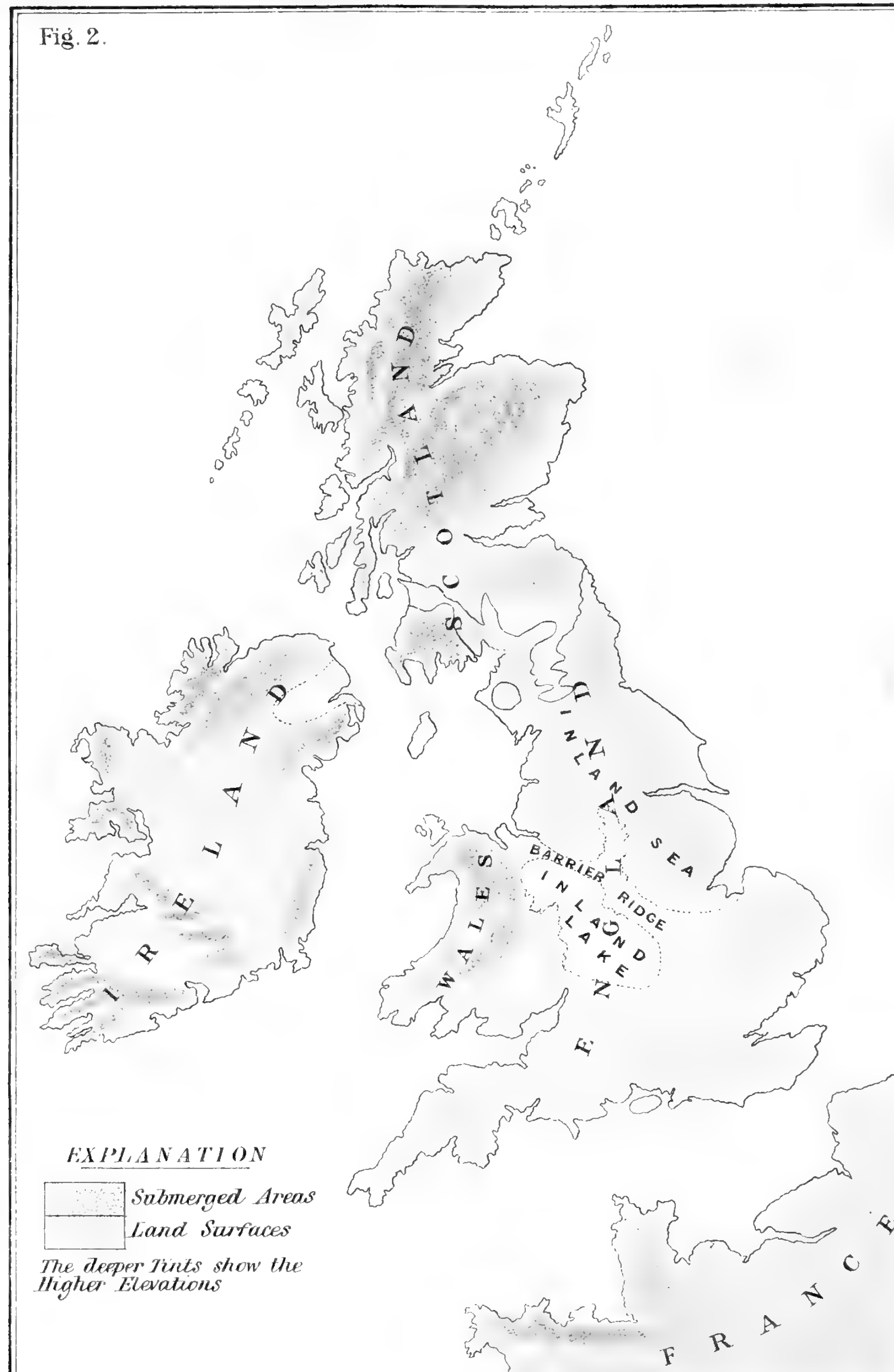

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Fig. 1.

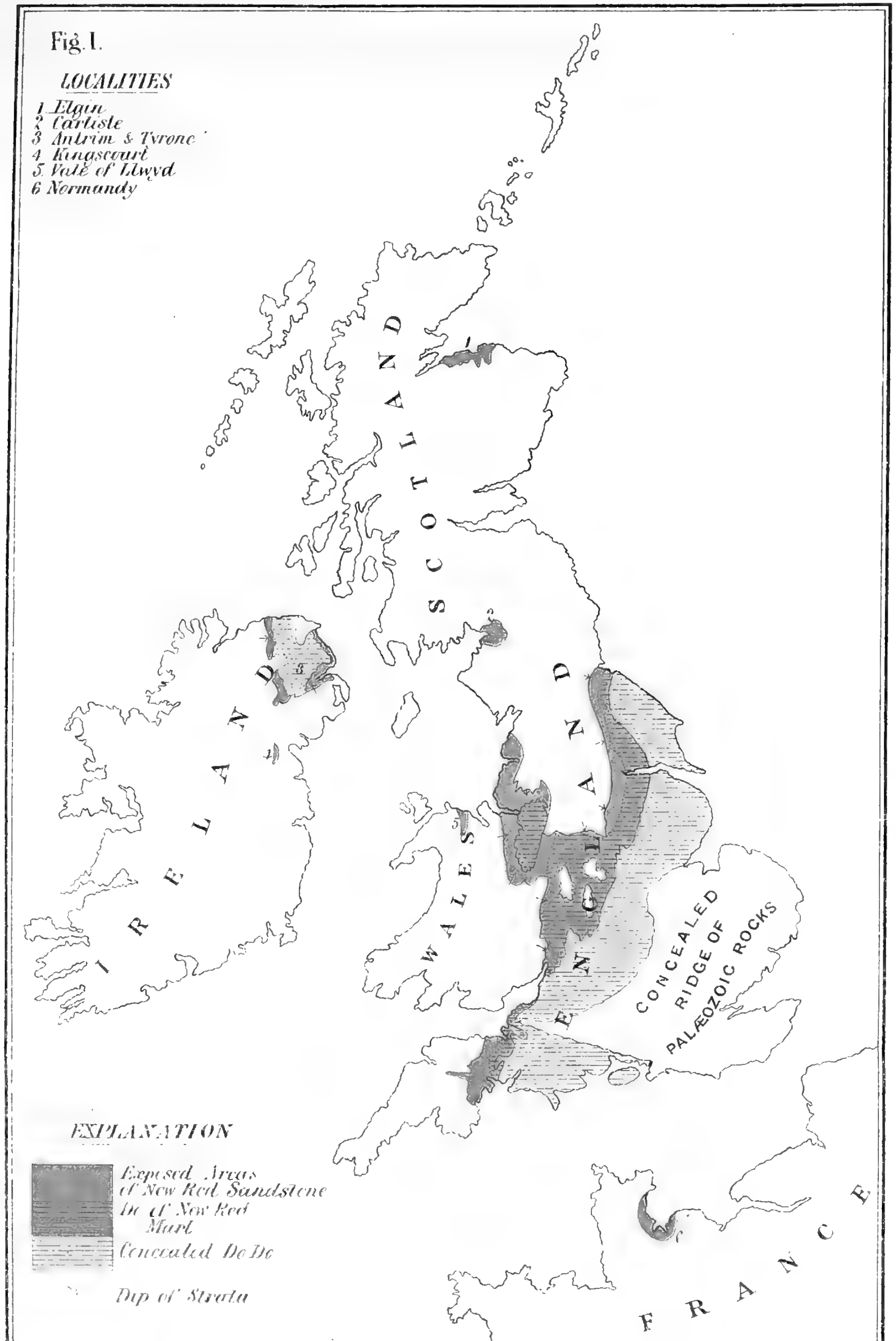
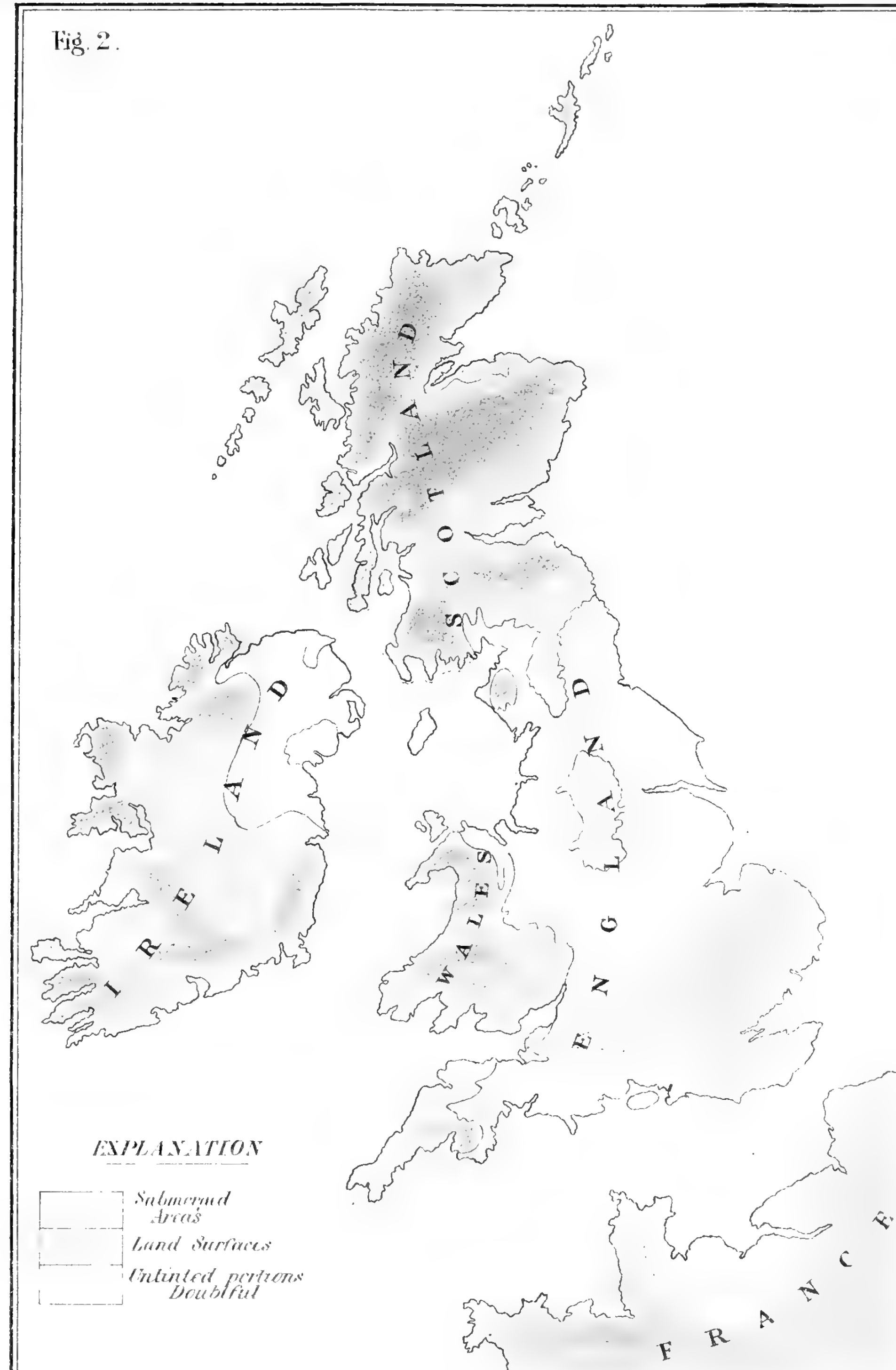


Fig. 2.



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PHYSICAL MAPS OF THE LIASSIC & OOLITIC *(Jurassic)* PERIODS.

Fig. 1.

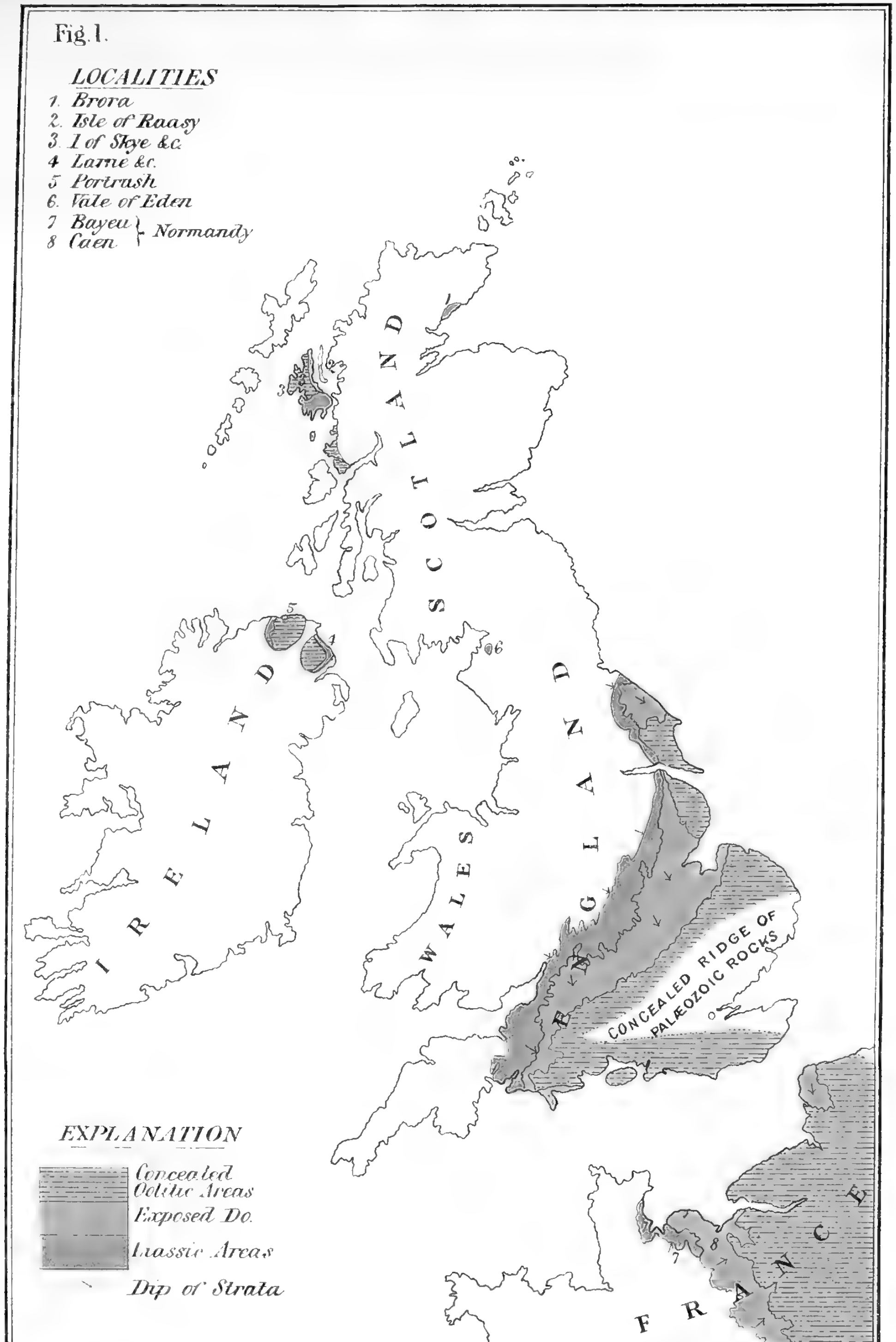
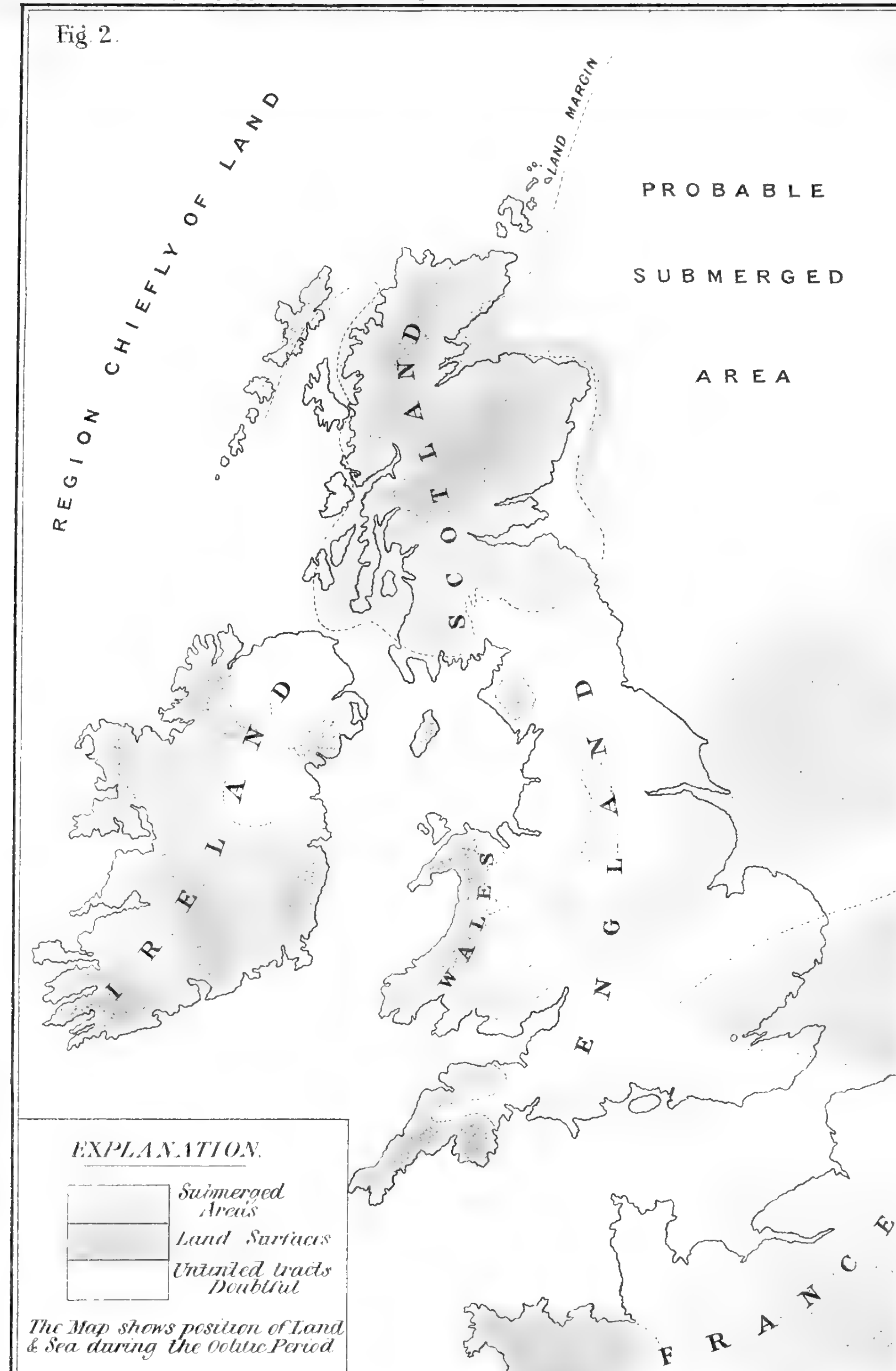


Fig. 2.



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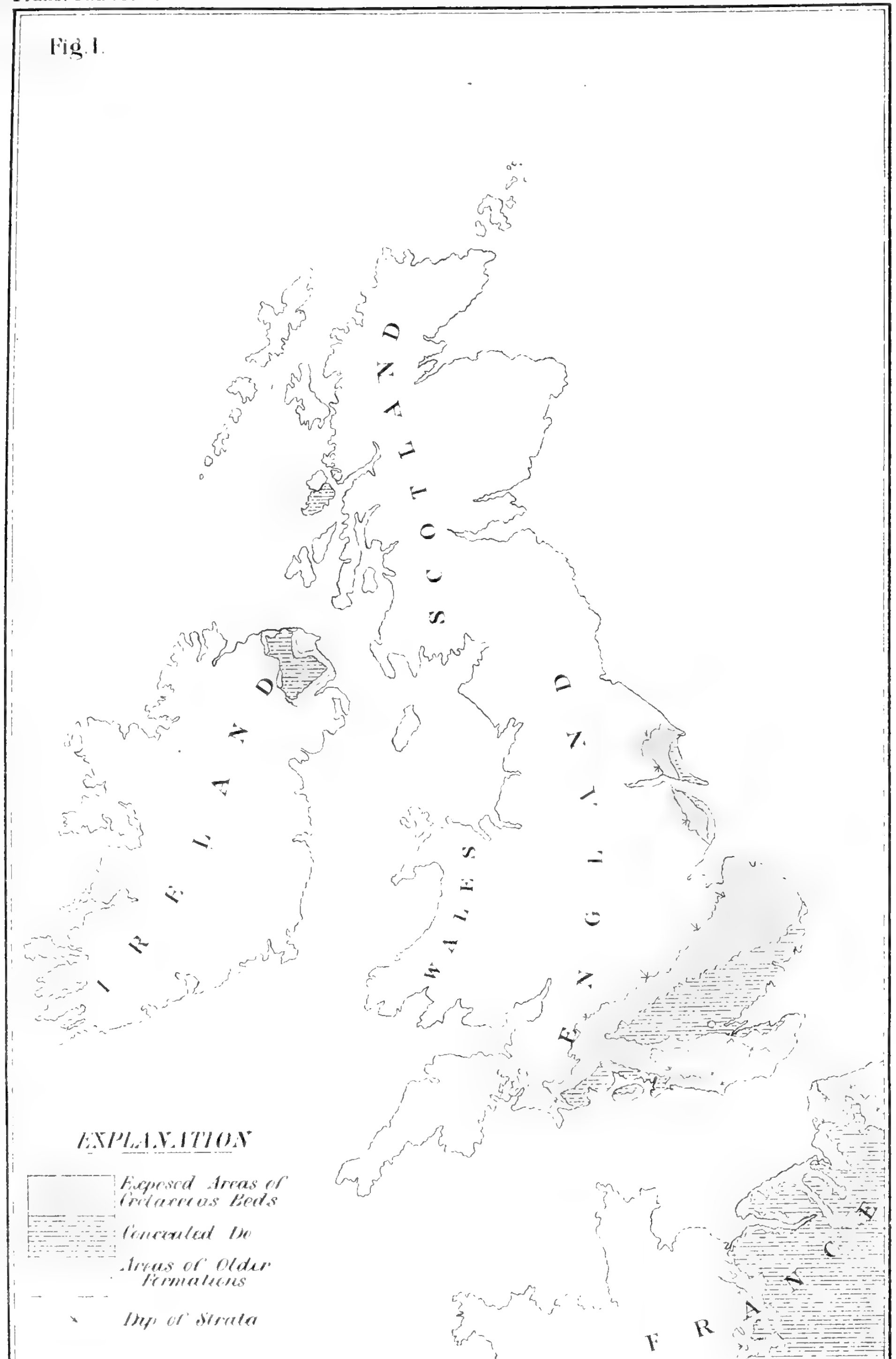
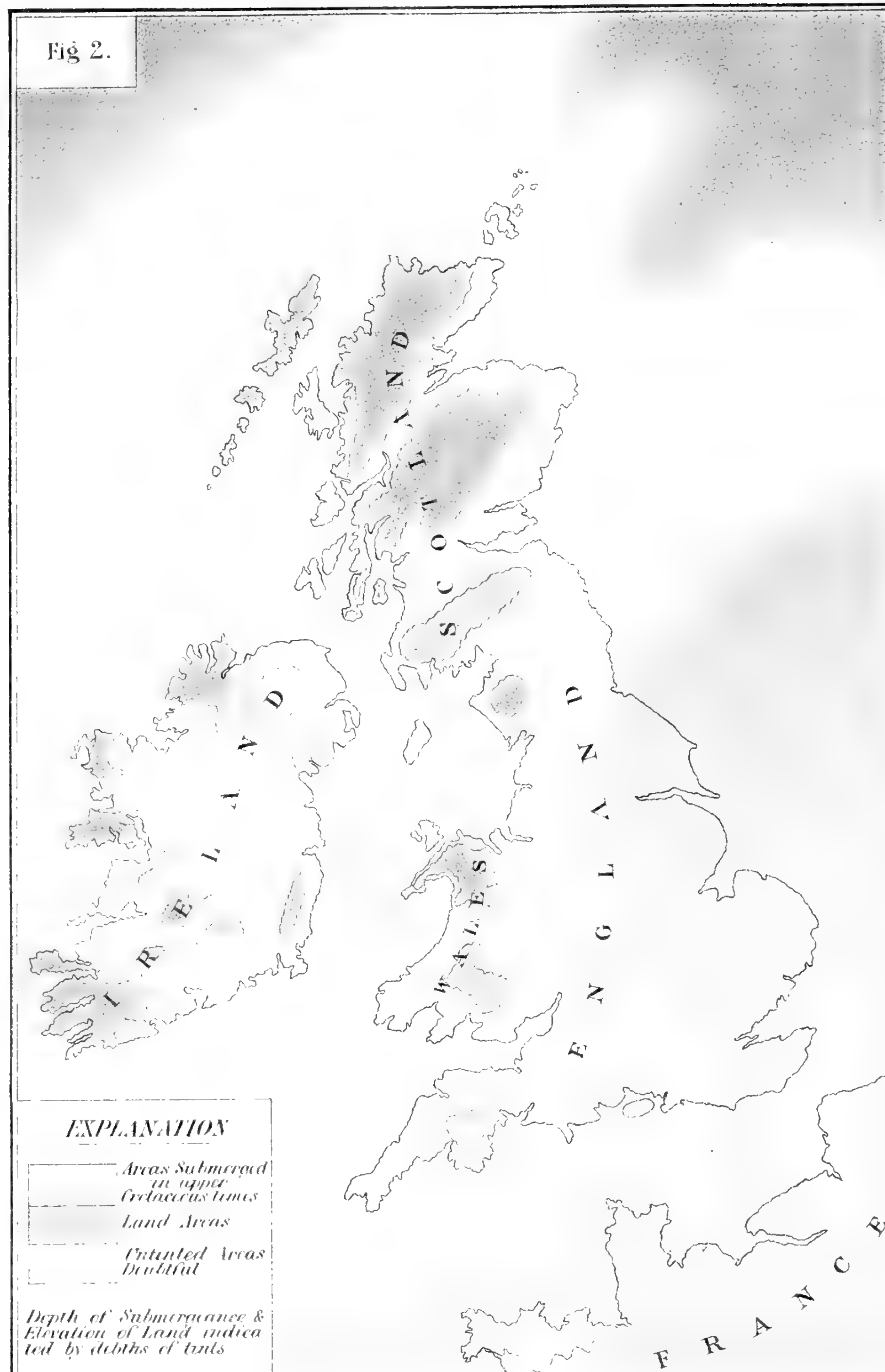
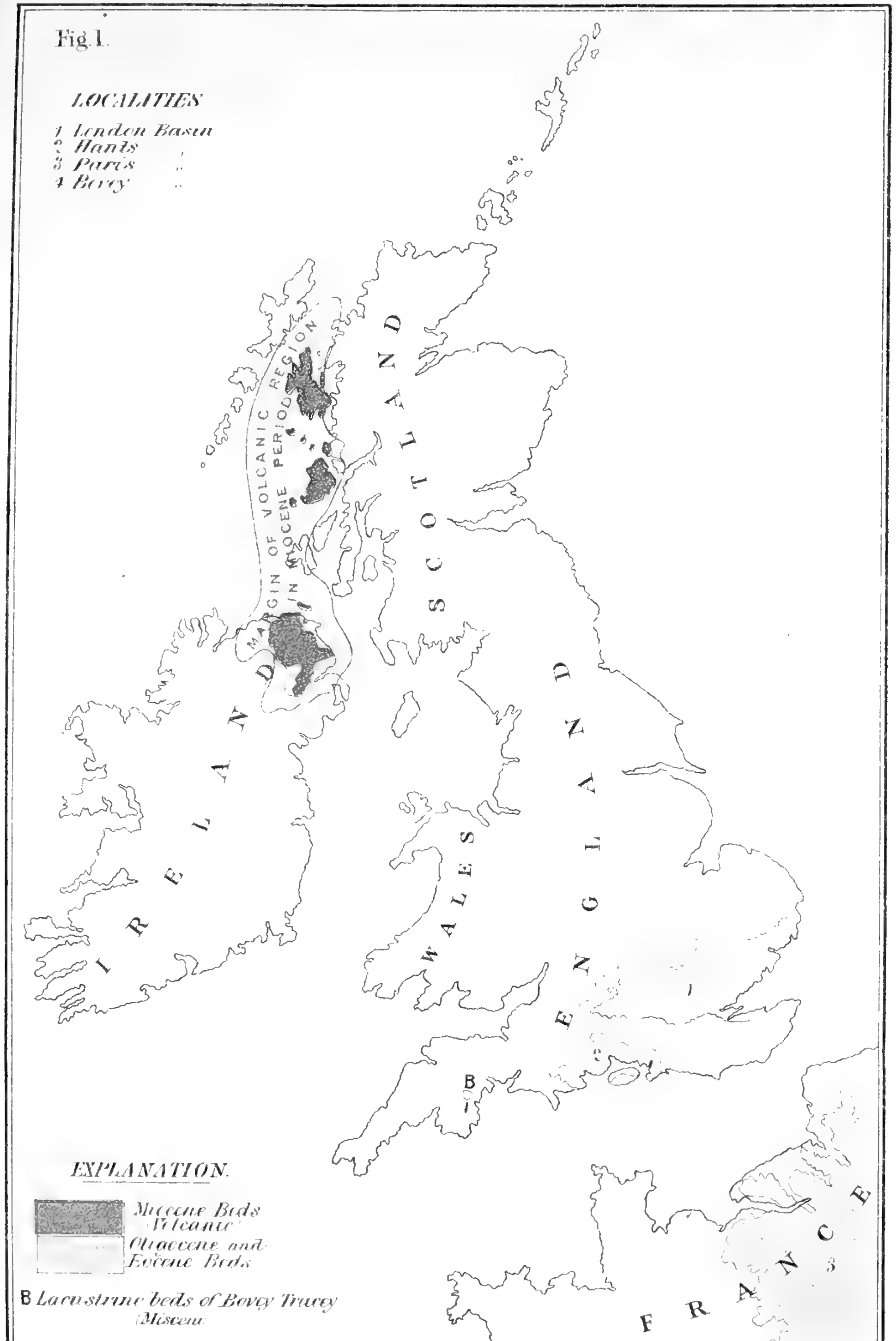
PHYSICAL MAPS OF THE CRETACEOUS PERIOD.

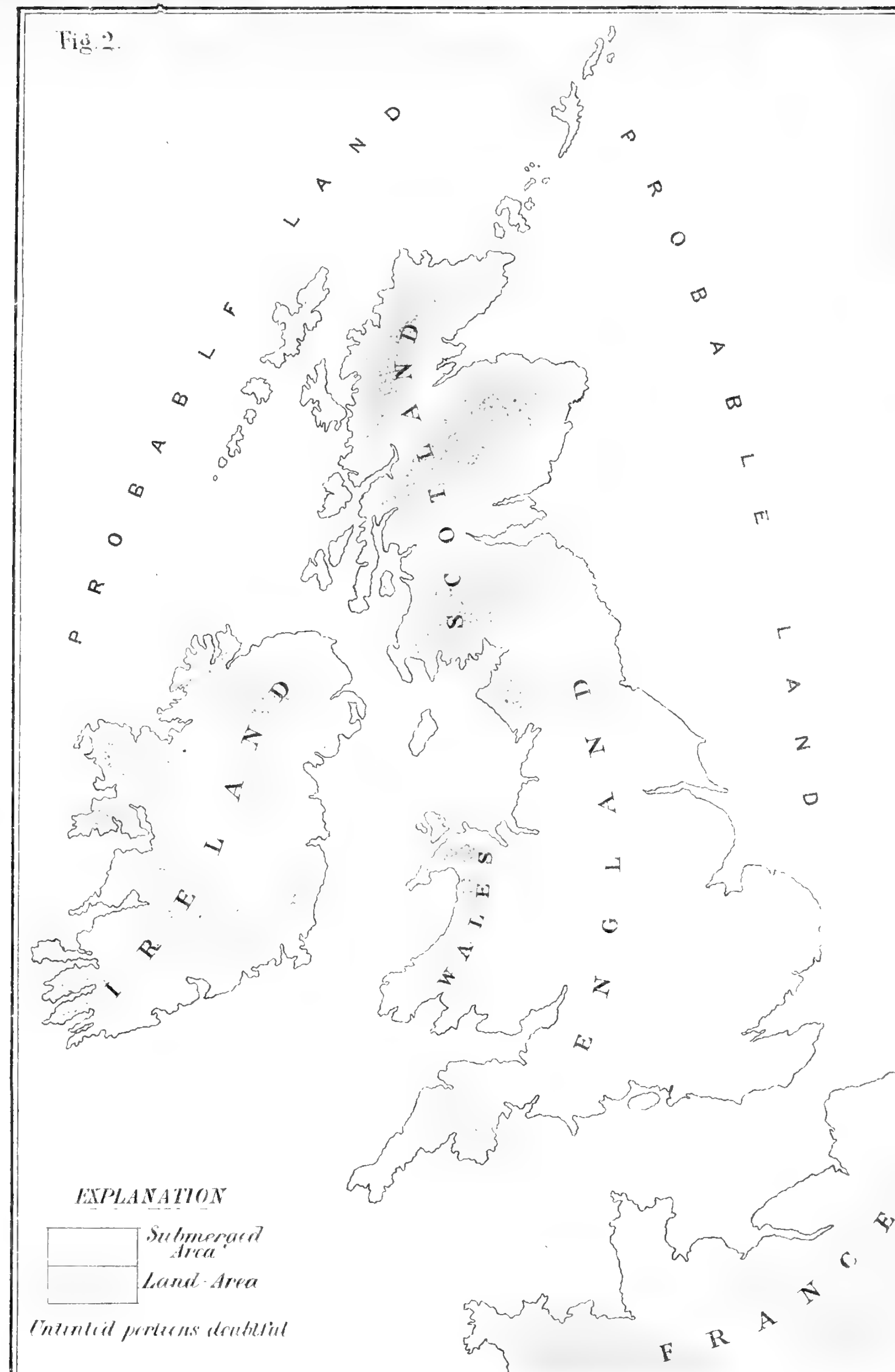




Forster & Co Lith Dublin

PHYSICAL MAPS OF THE LOWER & MIDDLE TERTIARY PERIODS.

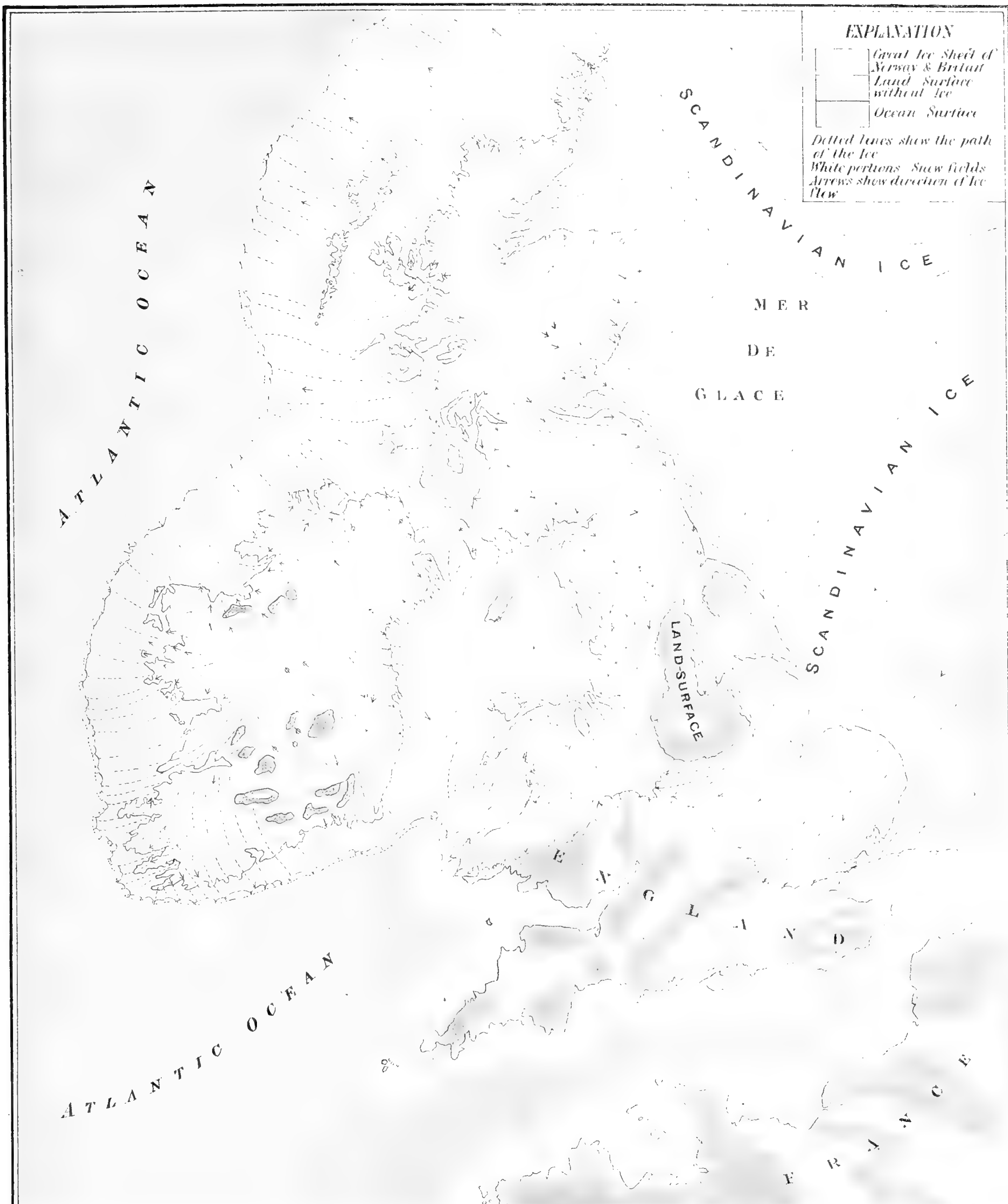




Forster & Co. Lith. Dublin

PHYSICAL MAP OF THE LOWER GLACIAL EPOCH.

Plate XXXIV.



Forster & Co. Lith Dublin

POST PLIOCENE OR DRIFT PERIOD (Continued)

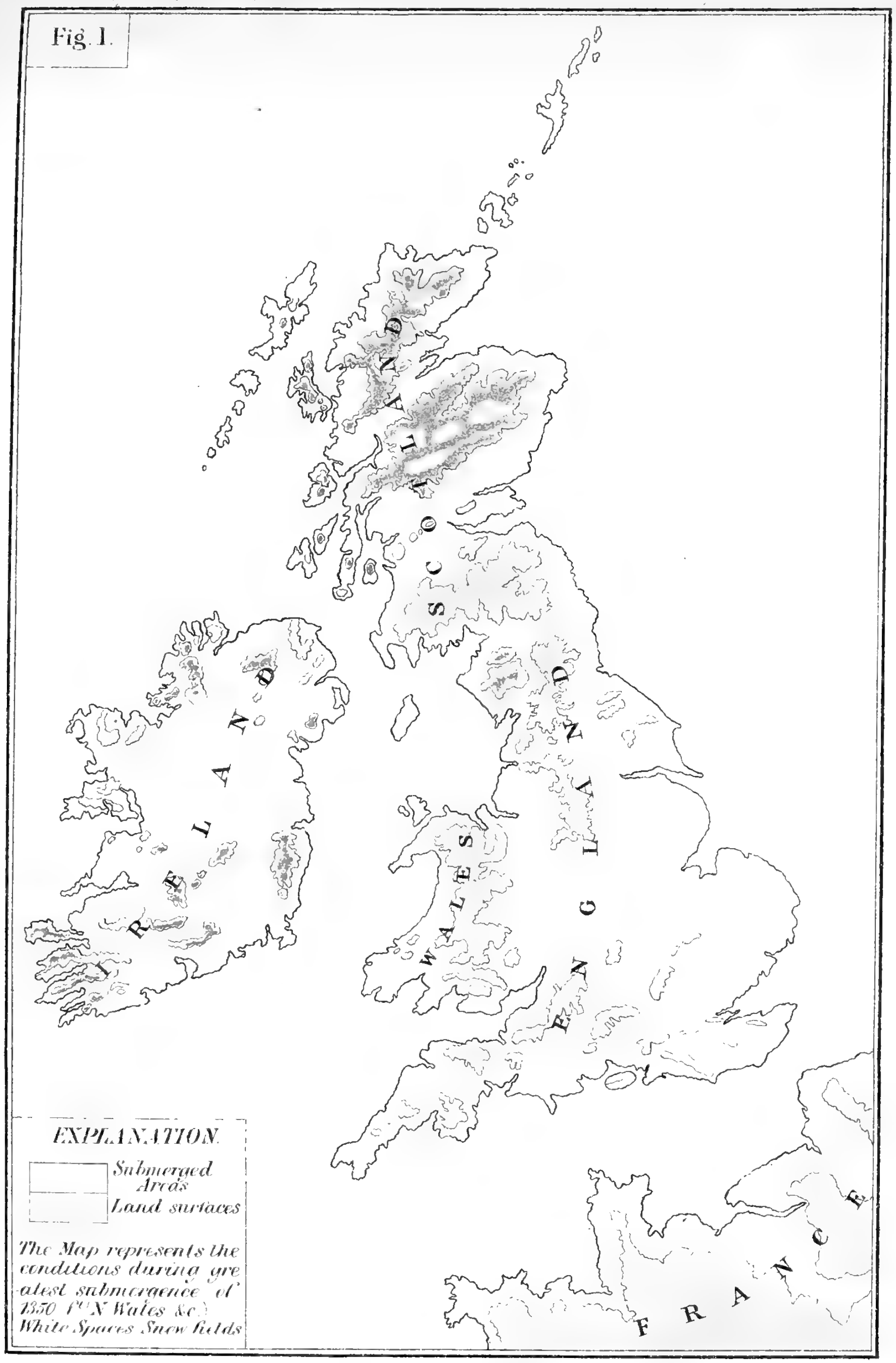


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Fig. 1. Map of British Isles, during epoch of Greatest submergence (Interglacial)

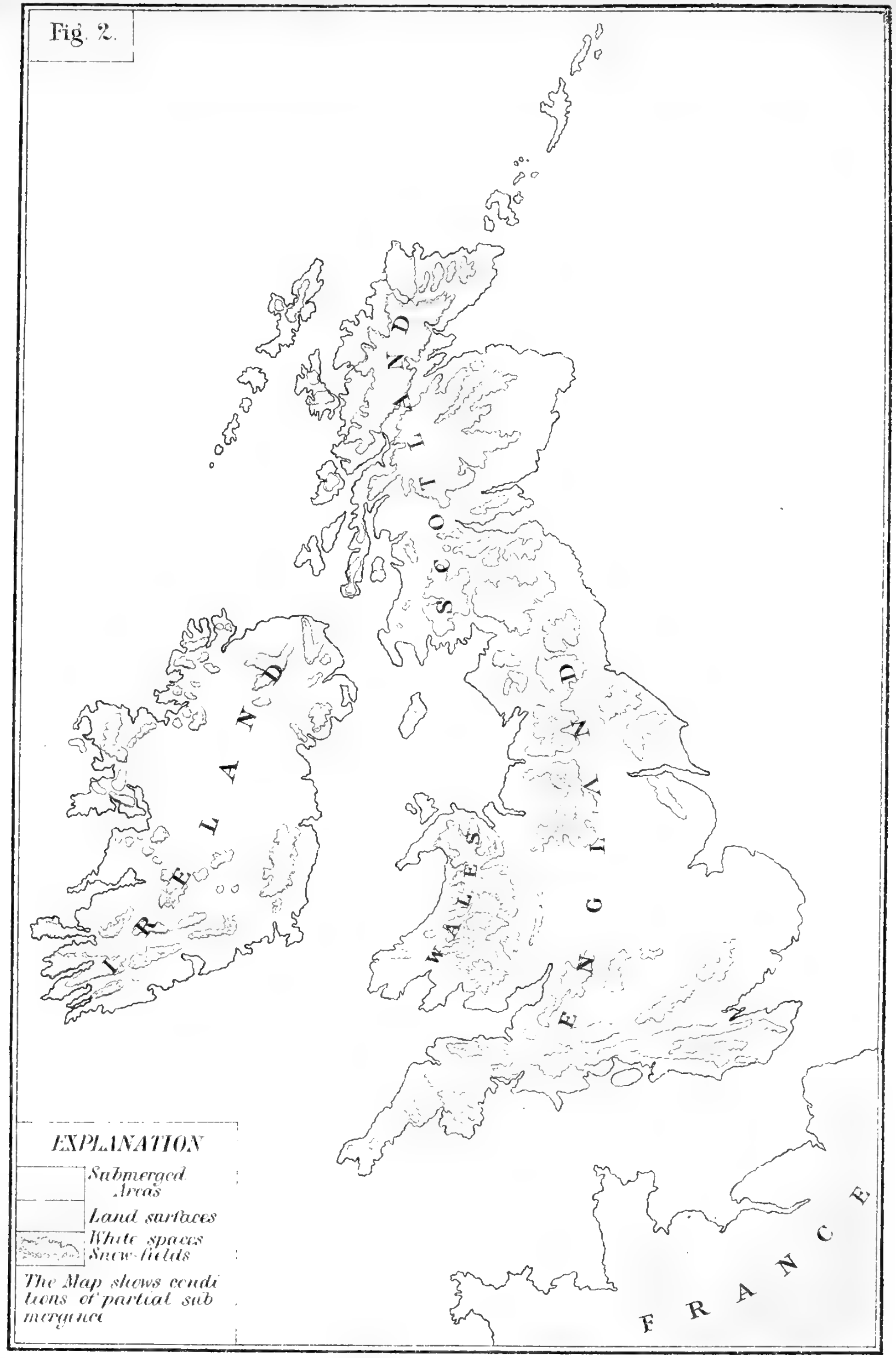

Fig. 2. Map of British Isles during epoch of sub glacial conditions (Upper Glacial)

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[December, 1882.]

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ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XX.—*Notes on the Physical Appearance of the Planet Mars during the Opposition in 1881. Accompanied by Sketches made at the Observatory, Birr Castle.* By Otto Bœddicker, Ph.D.—With Plates XXXVI. and XXXVII.

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XX.—NOTES ON THE PHYSICAL APPEARANCE OF THE PLANET MARS DURING THE OPPOSITION IN 1881. ACCOMPANIED BY SKETCHES MADE AT THE OBSERVATORY, BIRR CASTLE. BY OTTO BŒDDICKER, PH.D.—WITH PLATES XXXVI. AND XXXVII.

Communicated by the Earl of Rosse.

[Read April 17th, 1882.]

THE drawings of the planet Mars, which accompany these notes, were made with the reflector of three feet aperture at the Earl of Rosse's Observatory, Birr Castle, Parsonstown, from 1881, Nov. 19, to 1882, January 23, both days included. Unfortunately, the weather was very bad during this period, so that it was impossible to obtain more than twenty-one drawings, eighteen of which are here selected for publication. It would doubtless have been practicable to observe the planet with advantage after the 23rd January, if it had not also been frustrated by the unfavourable state of the atmosphere.

The speculum used is the same with which the drawings of Comets *b* and *c*, 1881, in these Transactions, Part XVII., (*antea* page 239 and Plate XIX.) have been executed; the power was in all cases 216.

The drawings are reproduced as they were made before the telescope. The most conspicuous spots were first put down and the time noted, and the more difficult details gradually filled in in the same degree as they could be discerned with certainty. The time spent upon each sketch was half-an-hour on the average. For sketching the stump alone was used, as with it the peculiar character of the markings could be best imitated. The amount of the phase has not been applied to the drawings, as they will hardly be of much value for the determination of areographic longitudes, being based on rather hurried eye-estimation only.

The following notes, in which the time referred to is mean Greenwich time, were made during the observations. The longitudes, after which the drawings are arranged, have been taken from Marth's Ephemeris in "Astronomische Nachrichten, No. 2,395."

1881, November 19.

Drawing No. 13.—Longitude, 287°·8. Time, $12^h\ 32^m$.

Pretty clear, but the smoke of the observatory chimney sometimes in the way.

The dark markings, especially the one on the central meridian, dark bluish; the large following continent (slightly shaded in drawing) very strikingly orange; limb very bright, especially north pole.

November 25.

No. 12.—L.= 257°·3. T.= 14^h 10^m.

Very clear, definition excellent.

Central continent reddish orange, with deeper coloured patches; the dark markings strikingly blue; the preceding edge of the "hour-glass" very bright, yet coloured; north pole rather bright.

November 30.

No. 9.—L.= 176°·4. T.= 11^h 43^m.

Clear; definition improving, partly very good.

Colours reddish, yellow, and blue; the north pole surrounded by a dark bluish-grey ring; the markings on the central part of the disc difficult to discern, of a deeper greyish ruddy colour.

No. 10.—L.= 209°·8. T.= 13^h 59^m.

Very clear, definition excellent.

Colours as before; divisions in the central continent reddish grey, in drawing a little too dark, not too distinct; the long interruption in the large southern ocean considerably bright.

December 9.

No. 6.—L.= 94°·1. T.= 11^h 33^m.

Definition moderate. Interrupted by clouds. It was exceedingly difficult to make out the details.

The disc orange, rather pale; the markings deeper orange, with the exception of the southern oval spot with surrounding parts, and the dark spot (np. to sf.) near the preceding limb, which were bluish and bluish-grey; the oval spot strikingly distinct, very dark bluish; the divisions n. and nf. more suspected than seen.

No. 7.—L.= 116°·3. T.= 13^h 4^m.

Definition sometimes very good, yet drawing very difficult.

The southern spots blue, the northern ones bluish-grey; the patches on the middle of the disc deep orange, difficult to discern; the divisions in the dark spot s. sf., next to the sf. part of it, very bright.

December 14.

No. 3.—L.= 44°·1. T.= 11^h 9^m.

Very clear, yet exceedingly difficult to make out details.

The dark n. and s. markings decidedly blue, the np. spot very dark; the central spots (following) deep orange; the sp. markings more suspected than seen.

No. 5.—L.= 83°·5. T.= 13^h 51^m.

Definition pretty good, drawing very difficult.

The dark sp. spot and the "eye" blue; the spot north of the "eye" and the np. one orange-grey; markings on the disc-middle deep orange; north pole spots only caught in glimpses; south limb of the "eye" very bright.

December 20.

No. 18.—L.= 356°·4. T.= 11^h 30^m.

Definition very good; cold squalls; tube and gallery at times trembling very much; interrupted by passing clouds; drawing under the most unfavourable and disagreeable circumstances.

The dark spots strikingly blue; the whole of the southern disc rather bluish; disc-middle orange; central hook-like spot very dark; the canals on the middle of the disc very difficult to be seen.

No. 1.—L.= 22°·3. T.= 13^h 16^m.

Definition good; interrupted and afterwards stopped by clouds; cold squalls; very disagreeable working.

The dark spots very blue; northern one very dark, as well as the sp. hook-like spot; sf. a very bright spot.

December 21.

No. 15.—L.= 326°·9. T.= 10^h 5^m.

Dense fog; definition excellent; image perfectly steady, like a map.

Markings visible up to the limb; the dark ones blue; the disc deep orange; the divisions on the middle of the disc faint and difficult; the southern spots rather faint, with very bright lines.

December 22.

No. 17.—L.= 355°·5. T.= 12^h 37^m.

Clear; definition, however, good during very short intervals only.

Sketch not at all in all parts equally reliable; the sp. and n. parts best, not so certain the sf. ones. There is apparently a connexion between the second hook and the nf. sea as in sketch.

December 26.

No. 14.—L.= 305°·3. T.= 11^h 36^m.

Definition good, though the image not very steady.

The dark spots greyish-blue; the large following continent orange; the faint markings on it, as well as the southern ones, very difficult.

No. 16.—L.= 338°·0. T.= 13^h 50^m.

Definition worse; image very unsteady. The aperture was reduced by diaphragm to 27 inches diameter, by which the image was decidedly improved; moments of great sharpness.

Colours deep orange (disc-centre) and blue; the northern spots very faint; near the south pole ill-defined patches which I could not make out.

December 27.

No. 11.—L.= 255°·8. T.= 8^h 49^m.

Definition very good.

The dark markings certainly blue; the np. spots on the large central continent

orange-grey; south prec., one very bright round spot. There is apparently an interruption in the "hour-glass." Its northern point seems to be disconnected from the dark northern spot preceding it. Is this latter spot in communication with the dark bay in the preceding border of the "hour-glass?"

January 9.

No. 8.—L.= 172°·7. T.= 10^h 57^m.

Very clear; definition sometimes very good.

The dark spots in north and south blue, the other markings deep orange or orange-grey; north pole and the south edge of the dark sf. spot very bright; markings on the disc-centre not easy, yet at moments quite distinct.

January 17.

No. 4.—L.= 61°·3. T.= 8^h 11^m.

Very clear; definition very good.

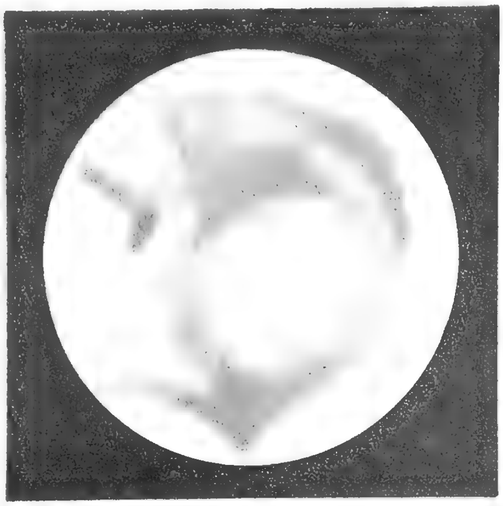
The southern spots and the dark np. one blue, the other markings—the spot north of the "eye" included—deep orange. There seem to be some lighter islands in the large southern sea; general appearance as in sketch; the dark canals some times very distinct.

January 23.

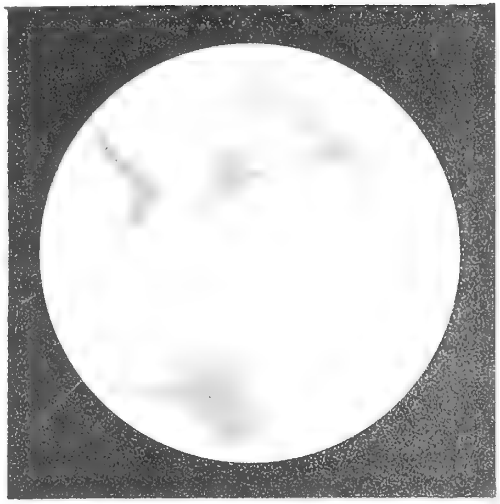
No. 2.—L.= 32°·6. T.=9^h 54^m.

Clear, but not quite steady; drawing difficult.

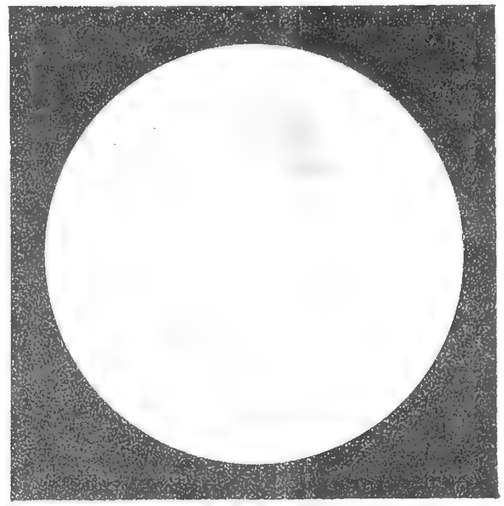
Spots blue and orange; disc rather pale; north pole (np.) very bright. All the southern spots perhaps somewhat too much south.



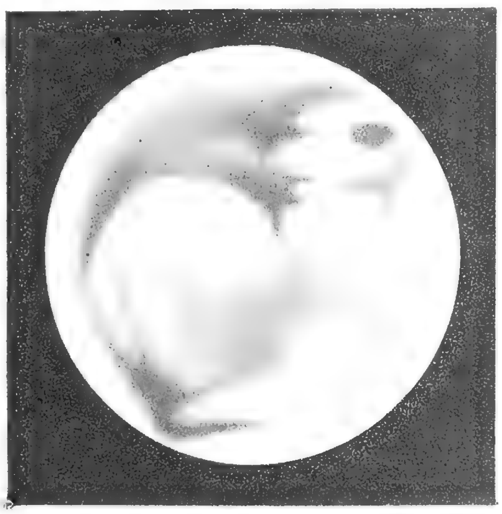
Nº 1. L. 22°,3. 1881 Dec. 20.



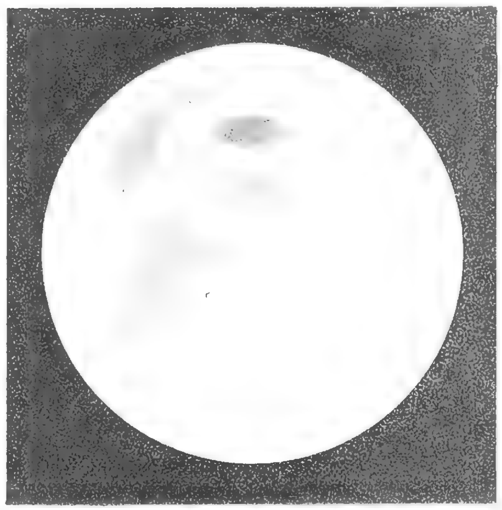
Nº 2. L. 32°,6 1882 Jan. 23



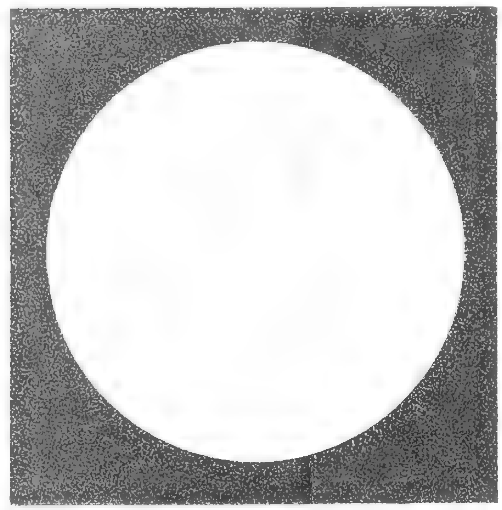
Nº 3. L. 44°,1 1881 Dec. 11.



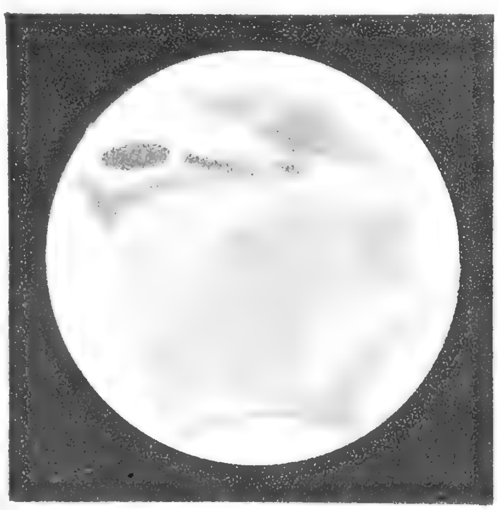
Nº 4. L. 61°,3 1882 Jan. 17.



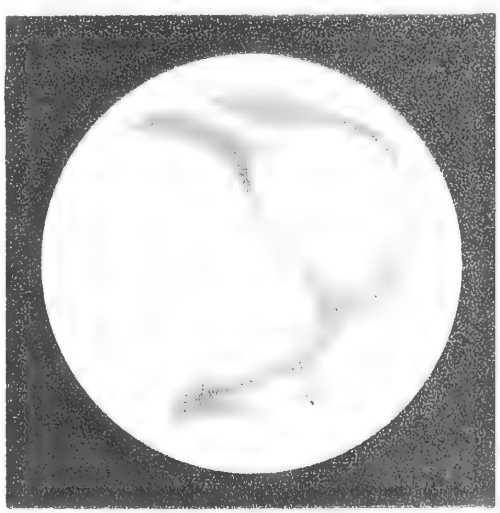
Nº 5. L. 83°5. 1881 Dec 14



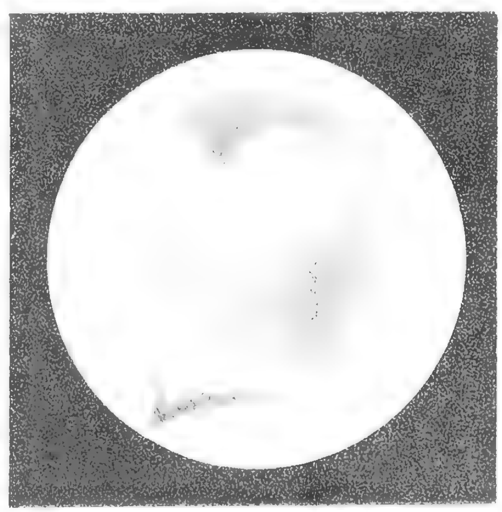
Nº 6. L. 94,1. 1881 Dec 9



Nº 7. L. 116°,3 1881 Dec 9.



Nº 8. L. 172°,7. 1882 Jan. 9.



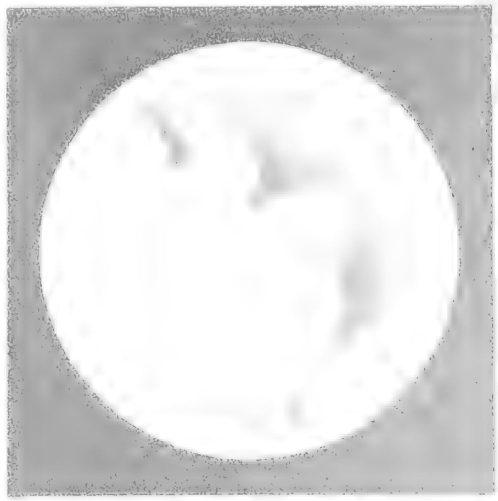
Nº 9. L. 176°,4. 1881 Nov 30

Otto Boeddicker del.

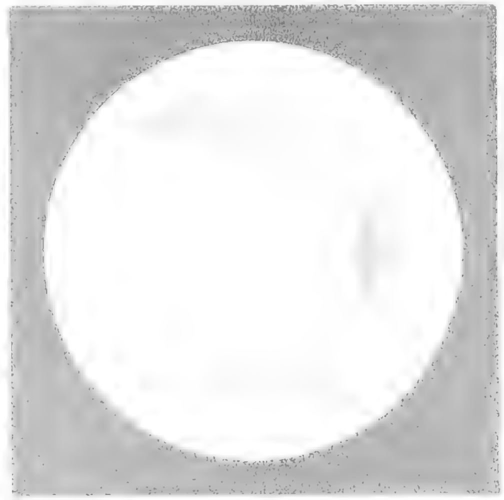
Mars.

Fredk Dangerfield Lith.

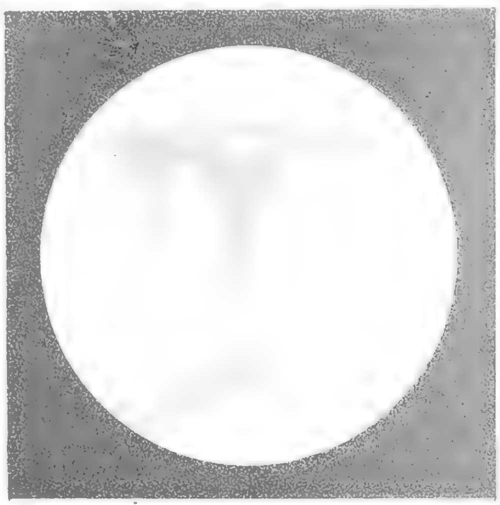
Nº 10. L = 209°.8. 1881 Nov. 30.



Nº 11. L = 255.8 1881 Dec 27



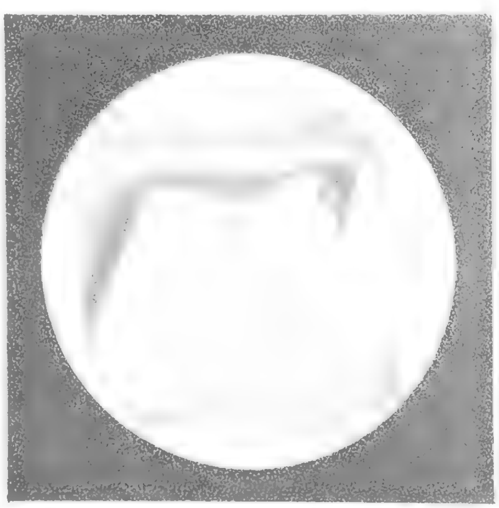
N. 12. L = 257.3 1881 Nov 25



Nº 13. L = 287°.8. 1881 Nov 19

Nº 14. L = 305.3. 1881 Dec 26

N. 15. L = 320.[illegible] 1881 Dec 2[illegible]



Nº 16. L = 338°.0 1881 Dec. 26.

Nº 17. L = 355.5. 1881 Dec 22

N. 18. L = 356.[illegible] 1881 Dec [illegible]

Otto Boeddicker del.

Mars

TRANSACTIONS (NEW SERIES).

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(Recently Published.)

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20.—Notes on the Physical Appearance of the Planet Mars during the Opposition in 1881. Accompanied by Sketches made at the Observatory, Birr Castle. By OTTO BŒDDICKER, PH.D. With Plates XXXVI. and XXXVII. (December, 1882.)

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2.—On Aquatic Carnivorous Coleoptera or Dytiscidæ. By Dr. SHARP. Plates VII. to XVIII. (April, 1882.)

[January, 1883.]

THE

SCIENTIFIC TRANSACTIONS

OF THE

ROYAL DUBLIN SOCIETY.

VOLUME I. (SERIES II.)

XXI.—*Notes on the Aspect of Mars in* 1882. By C. E. Burton, B.A., F.R.A.S., *as seen with a Reflecting Telescope of* 9-*inch Aperture, and Powers of* 270 *and* 600.—With Plate XXXVIII.

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XXI.—NOTES ON THE ASPECT OF MARS IN 1882. By C. E. BURTON, B.A., F.R.A.S., AS SEEN WITH A REFLECTING TELESCOPE OF 9-INCH APERTURE, AND POWERS OF 270 AND 600. WITH PLATE XXXVIII.

[Read April 17th, 1882.]

THE weather having presented obstacles to a detailed and minute survey of the planet at the late opposition, the number of drawings made has been smaller than on former occasions; but, as they represent features of some interest, especially when taken in connexion with the recent admirable researches of Signor Schiaparelli, I venture to lay them before the Royal Dublin Society.

It will not be advisable on the present occasion to enter on the question of areographical positions, as these have been determined for an immense number of points by Signor Schiaparelli, whose published results for 1877 and 1879 show that in no case has there been any change of position of a marking which could sensibly affect a discussion such as the present, by rendering identification difficult. I therefore propose to adopt a method of treatment which appears to be more suitable to the material, and to describe each of the markings or groups of markings in a separate section, adopting Signor Schiaparelli's nomenclature for readier comparison with his results, and for its superiority to that of personal names formerly used. Synonyms under the old system are given within brackets.

The Polar Snows.—The northern snow was seen constantly, and on two nights of particularly fine definition, was evidently somewhat complex and lobate in form, there being a deep indentation in the otherwise elliptical outline, approximately in longitude 300°, as if the white matter had melted more rapidly there than elsewhere under the influence of a sun now nearly at the northern solstice, the vernal equinox having been passed on the 8th of December, according to the calculation of Signor Schiaparelli. How rapid the diminution was may be judged of from the fact that at the beginning of February the Milan measurements assigned to it a diameter of 50°, with which my note, under date of Feb. 15^{d} 9^{h}, that "the N. snow was large and conspicuous," is in good agreement. A sketch made at the time gives the length of the diameter parallel to the planet's equator as about 30°, while those of March 11 and 13 (Pl. 38), respectively assign to it the diameters 15° and 20°. It may, apparently, be pretty safely assumed that the northern snow had, at the last mentioned date, shrunk to about one-ninth of its maximum dimensions, but with diminishing rapidity as the solstice approached. On March 13, I suspected that there was a minute dark speck in the centre of the snow, which last had an exces-

sively sharp outline. On April 7, the northern snow was brilliant, well-defined, lenticular in form, and bordered by a narrow dark band, widest at the preceding (western) extremity. The southern snow spot proper does not seem to have been visible either to Signor Schiaparelli or to the writer,* the white spots occasionally seen in the neighbourhood of the south limb by the first observer, having been identified with the bright spots designated as Thyle I. and II., Argyre I. and II., Novissima Thyle, and Hellas (Lockyer Land). Hellas seems to have been seen by me as a white space close to the south limb, on March 10, 11, and 13 (Pl. 38). On March 11 (Pl. 38), it contained an excessively minute and brilliantly white point. Japygia (Hirst Island) and the Yaonis Regio also contributed to increase the number of bright spaces seen.

Other White Spots.—Besides the brilliant points and areolæ seen constantly or from time to time near the north and south points of the limb, several possessing similar characteristics were observed within the Martian tropics, with one exception only, in positions where spots and markings of the same kind had been noted by previous observers. On March 8 (Pl. 38), between $8^h\ 28^m$ and $8^h\ 40^m$ G.M.T., a white lenticular space was observed, probably identical with that found by Schiaparelli, Knobel, and others to occupy the whole or a great portion of the region designated Elysium (Fontana Land) on the Milan chart; but on this occasion the whiteness was seen when the region was near to the west limb before sunset. A smaller and seemingly better defined white spot was detected on March 11 (Pl. 38): it is probably identical with that shown on March 13 (Pl. 38), as lying close to the northern extremity of Hesperia (Burchardt Land), and is possibly connected with the white streak shown by Mr. Green as bounding the north-eastern side of Hesperia, although probably seen as a separate spot for the first time on March 11 and 13 (Pl. 38). North-east of this white spot, another and less conspicuous one, identifiable with the Nix Atlantica, was visible on March 13 (Pl. 38). On the following side of the Syrtis Major (Kaiser and Dawes Seas) was, on March 11 (Pl. 38), a short white line, which lay somewhat obliquely to the coast line, touching it with its northern extremity. This whiteness, seen also on the 13th March (Pl. 38), has been repeatedly detected at previous oppositions by several observers, and appears to be independent of the planet's seasons, being well shown in Mr. Green's drawings of 1873 and 1877, near to the summer and winter solstices of the northern hemisphere.

The Dark Markings.—The Syrtis Minor was well seen on one occasion only, March 13th, and then had sensibly the same outline with that assigned to it in Signor Schiaparelli's chart of 1879. From its apex there ran, meridionally or nearly so, a dusky streak, apparently of equable breadth (the Lethe), which reached to the dark Arctic belt shown in the sketch of this date. There was also

* An additional reason for its invisibility to me was its proximity to the terminator and probable immersion in the planet's shadow at the several times of observation, if it had the same areographical position as in 1879.

visible a minute dark speck, sensibly in the position of the Lacus Tritonis, which had not been seen on March 11, although carefully looked for.

The Syrtis Major.—This fine marking (the Kaiser Sea + Dawes' Ocean) was well displayed on March 11 and 13, when its aspect agreed better with the drawings made in 1871, 1873, 1877, and 1879, by Messrs. Green and Knobel, and myself, than with the Milan views; Œnotria being invisible, and the darkest tone—rudely pear-shaped, with the narrow end to the north—lying next to the eastern coast, instead of turning south-westwards (Hind Peninsula), a portion of Libya projected into the Syrtis for some distance as a whitish spur, where the Milan charts of 1879 and 1882 have a nebulous shade, as if the encroachment of the Syrtis upon Libya had not only ceased, but the state of things had been reversed since the conclusion of the Milan observations. A similar advance of Libya (Hind Peninsula) upon the Syrtis Major was noted on May 25 and 28, 1873, by Mr. Green, and by me on May 29 of the same year. Towards the north the Syrtis Major appeared to bifurcate, and the two branches possibly joined the Arctic dark belt formed by the Sinus Alcyonius and Nilus. (But there was here a complication of minute detail which it was impossible to unravel satisfactorily, on account of the great distance of the planet and the perpetual slight flickering of the image.) From the preceding or western branch there proceeded a short dusky streak (March 11), possibly the Astapus; and from the following branch, Nilus, &c. (Nasmyth Inlet), arose two streaks, one seen on March 10 and 11—Colœ Palus with the northern portion of the Brison—the other (March 11 only), being probably the northern portion of the Euphrates (Lassell Sea ?). On March 10 a good view of the Sinus Sabæus (Herschel II. Strait) and the Margaritifer Sinus was obtained. The last mentioned bay was deep, and very sharp in outline. From its apex there ran in a north-westerly direction a perfectly straight dusky streak, narrow and less definite in outline than the bay reaching nearly to the Nilus. This dusky streak was probably the Indus, with its prolongation the Oxus, the former being visible only as far as the point where it bends abruptly to the north-east in the Milan chart (1879). The two points of the vertex of Argus (Dawes' Forked Bay) were not seen separately, and between this and the next preceding bay a whitish, ill-terminated promontory was very conspicuous.

In no case was the doubling of the dusky streaks, which has been the latest discovery due to Signor Schiaparelli, and found by him to have a connexion with the change from winter to summer, detected by me—a circumstance not surprising when the minute diameter of the planet is taken into account, even supposing that the duplication in question had continued so long. It would seem from the remarks of Signor Schiaparelli, in his preliminary note communicated to the Accademia dei Lincei, and read at the meeting of March 5, 1882, which he has kindly forwarded to me, that the duplication referred to endures for a very short time (probably not much more than a Martian month), and that it commences with considerable abruptness. In some cases Signor Schiaparelli has been able to

follow the process through all its initial stages, and gives the following description of it :—

"On the 13th January (1882), a very faint and ill-defined shade appeared to extend parallel to the Ganges; on the 18th and 19th these parts were covered with white spots and were no longer visible. On the 20th, I find it written that the Ganges appeared to be composed of two parallel lines, but the matter was doubtful, and not taken account of for that reason. On the 21st, the duplicity was evident, and so remained even on the 23rd of February. Similarly, the Euphrates was broad and dark on Jan. 19th, ill-defined and nebulous on the left hand side. On the 21st, there had already appeared, on the left hand side, a companion 'canal,' and the Euphrates was the resultant of two equally broad and dark lines, each of which was indeed somewhat less intense than the single line of Jan. 19th. A similar nebulosity appeared to precede the duplication of the Canal of the Titans and the Pyriphlegethon."

These results are foreshadowings of what may be expected if it shall ever be practicable to employ the whole optical power and perfection of definition of the many large telescopes now in existence in studying the planet under favourable conditions. How rare such conditions are in our climate is, unfortunately, only too well known, no instrument of the class referred to having given more than momentary glimpses of those minute details which will require prolonged study in order to make further advance in knowledge of the constitution of this planet—details so minute and complex that the smallest tremor of the image suffices to confuse and render them undecipherable.

During my observations, the power of 600 was generally used whenever the state of the air would admit of it. Professor Schiaparelli employed a power of 417, with an achromatic of 8·9 inches aperture.

Notes added in Press.

Longitudes of the central meridian of Mars with the corresponding diameters of the disc at the epochs of some of the sketches and notes referred to in the preceding paper. Greenwich mean time throughout.

Epoch.	D.	H.	M.	Longitude (λ). °	Diameter. ″
1882—Feb., .	15	10	5	185·5	10·44
March, .	7	8	34	336·5	8·66
,, .		9	18	347·2	8·65
,, .	10	11	15	357·4	8·41
,, .	11	8	50	302·7	8·36
,, .	13	8	40	281·4	8·22
April, .	15	10	50	358·7	6·39

Hourly change of $\lambda = 14^{\circ}{\cdot}61$ nearly.

1881.	December 8,	Spring Equinox	of Mars' Northern Hemisphere.
1882.	June 25,	Summer Solstice	

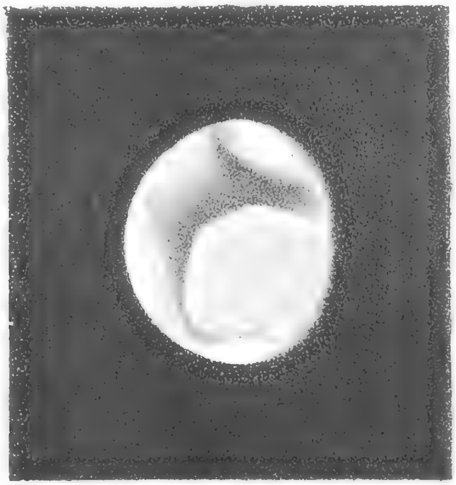
The data for the above have been taken from Mr. Marth's Ephemeris for Physical Observations of Mars in 1881–2, published in the *Astronomische Nachrichten.*

June 19, 1882.

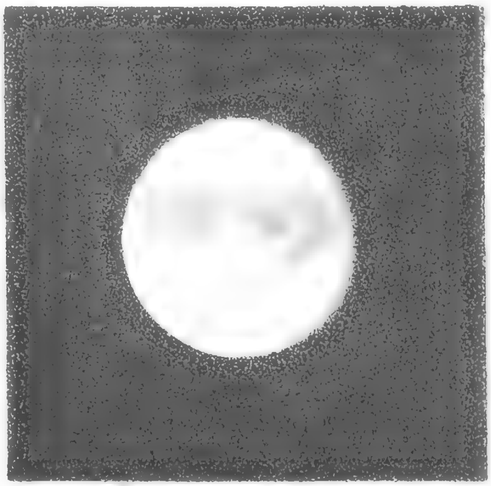
ADDENDUM.

Dr. Terby, of Louvain, has kindly pointed out an erratum in my paper on Mars (these Transactions, *antea* Pt. XII., page 151), that the light streak in Fig. 12, Plate VI., is probably Atlantis I. a permanent feature. The longitude of the central meridian for the epochs of Figs. 12, 14, and 15, Plates VI. and VII., should respectively be increased by 16°, when they will stand thus :—

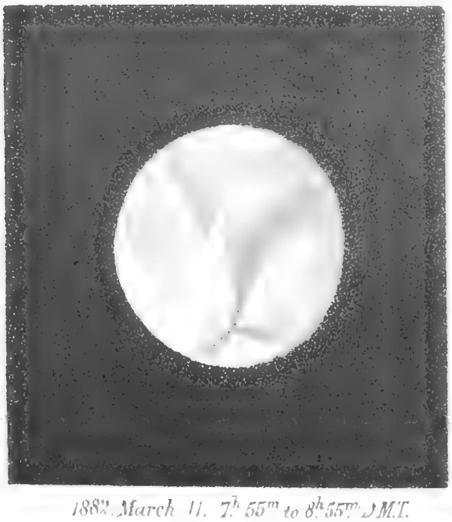
Fig. 12.	Longitude, ...	=158°
,, 14.	,, ...	=169°
,, 15.	,, ...	=197°



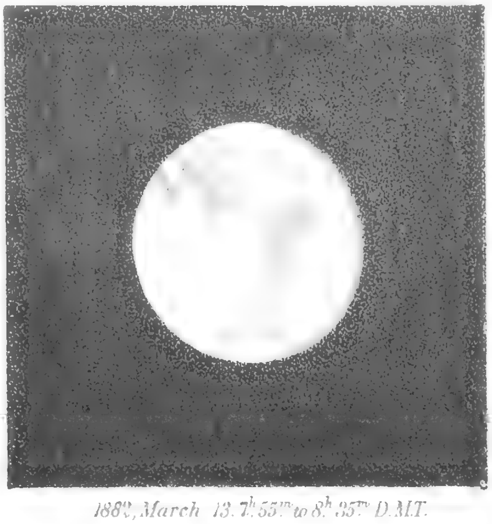
1882, March 8. $8^h 3^m$ to $8^h 15^m$ D.M.T.
(Partially finished.)
1.



1882, March 10. $10^h 50^m$ D.M.T.
(Unfinished.)
2.



1882, March 11. $7^h 55^m$ to $8^h 55^m$ D.M.T.
3.



1882, March 13. $7^h 55^m$ to $8^h 35^m$ D.M.T.
4.

E. Burton del.

Mars.

Fredk Dangerfield London

TRANSACTIONS (NEW SERIES).

VOLUME I.

(*Recently Published.*)

VOLUME II. (*complete.*)

[JANUARY, 1883.]

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XXII.—*On the Energy expended in Propelling a Bicycle.* BY G. JOHNSTONE STONEY, D.SC., F.R.S., A VICE-PRESIDENT OF THE SOCIETY; AND G. GERALD STONEY.—WITH PLATES XXXIX., XL., and XLI.

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XXII.—ON THE ENERGY EXPENDED IN PROPELLING A BICYCLE.

By G. Johnstone Stoney, d.sc., f.r.s., a Vice-President of the Society; and G. Gerald Stoney.—With Plates XXXIX., XL., and XLI.

[Received August, 1882.]

The magnitude of the effects produced by human muscles acting upon bicycles and tricycles is well deserving of attention. Several riders of exceptional strength and endurance have travelled considerably more than 200 miles in one day, along common roads; another has twice maintained an average speed of more than twenty miles an hour along a prepared path for a whole hour; another has ridden from the Land's End to John O'Groat's, a distance of almost 1,000 miles, in thirteen days, averaging more than seventy-six miles a day. These astonishing feats have been accomplished upon bicycles, and the tricycle does not fall far behind. A tricycle has been ridden a distance of 180 miles in one day; and hundred mile journeys on both classes of machines have become frequent. It is perhaps quite as striking that average riders, who are not athletes, even including those who are between fifty and sixty years of age, usually in touring make from thirty to sixty miles a day without pressing themselves, going on day after day without intermission and without fatigue.

Such an astonishing efficiency ought to be capable of explanation; and as it is plain that no sound knowledge on the subject can be gained without first ascertaining experimentally the amount of energy actually expended in propelling a bicycle, we have endeavoured to make this determination.

The machine known as the "Xtraordinary" offers facilities for attaching an indicator diagram apparatus to it, and was that upon which the experiments were made. It is represented in Figure 1, Plate 39. Indicator diagrams were obtained in two different ways, which furnished independent series of observations, adapted to test each other. Further to confirm our results, we endeavoured to measure the energy by a kinetic method, by taking the feet off the treadles when the machine was running at high speed, and leaving it to advance by its own impetus (*i.e.*, kinetic energy) until the rate was too slow for the rider to maintain a steady balance. After some practice the skill required to carry out this programme was attained, and the observations were made by an assistant noting the times occupied in performing successive sets of five revolutions of the wheel. Starting with a speed of about fourteen miles an hour, four, and in some cases five, such sets could be observed before the motion became unsteady. From these data the energy required to drive a bicycle at the speeds successively passed through could be deduced. The results which we were able to obtain by this method, so far as they go, seem to confirm the more reliable deductions from the indicator diagrams, but

we do not believe them to be worth publishing as we had not adequate appliances for measuring fractions of a second of time, which would have been necessary to give the observations a satisfactory amount of accuracy. The method, however, is good, and as we have found that other practical difficulties can be overcome, it would probably be worth repeating* these observations with the assistance a chronograph.

The first apparatus which we made for furnishing indicator diagrams was attached at the top of the right hand lever of the bicycle. The link which trammels the top of the lever was removed and a spiral spring substituted for it, which was compressed when the right foot acted on the pedal. To the lever a vertical flat board was fastened to carry the paper on which the diagram was to be produced; and the diagram was drawn by a pencil connected with the inner end of the spring. Thus the pencil was relatively at rest and the diagram paper was moved past it in two directions—in the arc of a circle corresponding to the up-and-down motion of the lever, and radially corresponding to the force applied. The apparatus is represented in Pl. 39, Fig. 2, and the diagram it produced in Figure 3. This may be called the crude indicator diagram from which the true indicator diagram represented in Figure 4, Pl. 40 has to be derived.

This was accomplished by hanging known weights on the pedal to represent the pressure of the foot, and moving the wheel round so as to get the lines corresponding to known forces exerted on the pedal. The successive dotted lines of Pl. 39, Fig. 3, were in this way drawn, when one, two, three, four, five, stones were successively hung on the treadle. In the reduced indicator diagram (Pl. 40, Fig. 4) these become parallel equidistant lines, and are the dotted lines of that figure. Horizontal distances in Figure 4 would be strictly proportional to the forces applied by the foot if it had acted vertically, but if the foot acts obliquely the force as registered in this way may be somewhat greater than the actual force exerted. Hence the energy as indicated in this way might slightly exceed the true value, though, as the result proves, it has done so either not at all or but little. It was chiefly to detect and avoid this possible error that the second series of indicator diagrams described below was undertaken, contrived so that the indicated energy must fall somewhat short of the true value. A comparison of the two series shows that any such excess or defect is small in either series.

To return to Figure 4, Plate 40. Vertical distances on Figure 4 have been made proportional to the net† vertical distances through which the foot descends. This was accomplished by the help of Figure 5 which represents the oval curve through

* We have since made these observations, see the Addendum to this paper, page 314.

† By the net descent of the foot is to be understood the distance through which the foot would descend if the spring were not compressed. The additional distance through which the foot descends, owing to the compression of the spring, represents additional energy exerted by the rider on the down stroke, which, however, the spring restores to the foot on the up stroke, when by its resilience it assists the lifting of the leg. It accordingly is not work done on the bicycle and should not be counted in.

which the foot travelled before the indicator apparatus was attached, with points marked on it corresponding to the points numbered in the same way on the circle of the figure, which is the curve through which the end of the crank of the bicycle travels. And again the same numbers on Figure 3, Pl. 39, mark the points of the indicator diagram corresponding to those positions of the crank. These on the "reduced" diagram, (Pl. 40, Fig. 4,) are made proportional to the net vertical descent of the foot in its oval motion. The area of the "reduced" diagram, Figure 4, will then be the energy supplied by the right foot of the rider during one revolution of the bicycle wheel, on the hypothesis that he presses vertically on the treadles; and the whole energy exerted by both feet will of course be twice this.

The following results were obtained with this apparatus in the winter of 1881–82, and the diagram represented in Figure 3, Plate 39, is copied from that produced in experiment 6.

TABLE I.

Series I. of Observations made in Winter with the Recording Spring attached to the top of the Lever of the Bicycle.

No. of Experiment.	Energy per Mile.	Energy per Minute.	Velocity in Miles per Hour.	Coefficient of Resistances.	Observations.
1 2 3	21,800 23,700 40,500	3,500 4,000 7,900	9·6 10·2 11·7	$\frac{1}{48}$ $\frac{1}{44}$ $\frac{1}{26}$	On wet gravelled pathway in Palmerston-park, Dublin, up a trifling inclination of 1 in 160, with the wind.
4 5 6 7 8 9	19,200 29,500 36,000 38,500 38,500 41,600	2,650 4,000 5,350 6,000 6,500 7,400	8·3 8·2 9 9·4 10·2 10·7	$\frac{1}{54\cdot3}$ $\frac{1}{35\cdot4}$ $\frac{1}{29}$ $\frac{1}{27}$ $\frac{1}{27}$ $\frac{1}{25}$	On the same path, down the incline, and against the wind.
10 11 12	28,800 31,000 38,500	3,750 4,850 5,350	7·8 9 8·3	$\frac{1}{36\cdot2}$ $\frac{1}{34}$ $\frac{1}{27}$	In the direction of the wind, on muddy rough level road in Palmerston-park.
13 14 15 16	38,500 45,000 54,000 57,600	4,000 6,700 7,000 7,200	6·25 9 7·8 7·5	$\frac{1}{27}$ $\frac{1}{23\cdot3}$ $\frac{1}{19\cdot4}$ $\frac{1}{18}$	Against the wind, on the same road.
--	36,000	5,350	9	$\frac{1}{29}$	Average of all the foregoing experiments.

In the other series of experiments made in July, 1882, a spring was placed directly under the treadle so that its compression was proportional to the vertical component of the force exerted by the foot. It moved the pencil horizontally by a bell-crank lever while the paper was carried up and down by a secondary crank fastened to the end of the crank of the bycicle. Thus the distances in one direction on the indicator diagrams represent the vertical force of the foot, and distances at right angles represent the vertical heights of the end of the bycicle crank. The apparatus is represented in Figure 6, Pl. 40, the diagram it produces in Figure 7, Pl. 41, and the reduced indicator diagram in Figure 8, Pl. 41. The reduction was effected as before by the help of Figure 5, Pl. 40. It will be observed from the position of the rider, and since the vertical component of the foot's pressure is what is registered, that the results furnished by this method cannot *exceed* the truth. They are as follows, No. 29 of the series being that represented in Figure 7, Pl. 41. That the results of this series are so close to those of Table I. shows that both must be near the truth.

TABLE II.

SERIES II. of Observations made in Summer with the Recording Spring attached to the Treadle.

No. of Experiment.	Energy per Mile.	Energy per Minute.	Velocity in Miles per Hour.	Coefficient of Resistances.	Observations.
17 18 19	16,000 20,500 47,000	1,850 3,600 10,400	7 10·4 13·3	$\frac{1}{65}$ $\frac{1}{51}$ $\frac{1}{22·3}$	Observations on dry hard gravelled path in Palmerston-park, down a trifling inclination of 1 in 160; calm.
20 21 22	18,000 25,600 45,000	2,000 4,700 10,400	6·7 11·3 14	$\frac{1}{58}$ $\frac{1}{41}$ $\frac{1}{23·3}$	Up the same incline; calm.
23	36,000	6,000	10	$\frac{1}{29}$	Down the incline when wet; calm.
24 25	27,000 32,000	3,100 5,000	7 9·4	$\frac{1}{39}$ $\frac{1}{32·6}$	On dry level road in Palmerston-park; calm. The road was in good order for roads in that neighbourhood.
26 27 28	24,300 28,000 47,000	3,300 4,600 10,400	8·2 9·9 13·4	$\frac{1}{43}$ $\frac{1}{37}$ $\frac{1}{22·3}$	On the same road, in the direction of a light wind.
29 30 31	36,000 38,400 51,200	5,350 5,500 9,000	9 8·6 10·4	$\frac{1}{29}$ $\frac{1}{27}$ $\frac{1}{20·4}$	On the same road, against light wind.
–	33,000	5,100	9	$\frac{1}{32}$	Average of the preceding experiments.

TABLE II.—PART II.

Experiments made on Hills with the same Apparatus.

No. of Experiment.	Energy per Mile.	Energy per Minute.	Velocity in Miles per Hour.	Coefficient of Resistances.	Observations.
32	45,000	6,400	8·5	$\frac{1}{23 \cdot 3}$	Up lower part of Dartry-hill, inclination slight (1 in 48), surface rough; calm.
33 34 35	49,000 51,200 57,600	5,850 7,300 10,000	7·2 8·5 10·4	$\frac{1}{21 \cdot 4}$ $\frac{1}{20 \cdot 4}$ $\frac{1}{18}$	Up hill at Landscape gate, inclination gentle (1 in 26), surface fair; calm.
36	64,000	6,700	6	$\frac{1}{16 \cdot 3}$	Up hill at Milltown Station, inclination considerable (1 in 17), surface as smooth as a path; calm. N.B.—The spring reached the end of its range in this experiment, so that the actual energy applied was somewhat more than that recorded here.
37	62,000	6,900	6·7	$\frac{1}{16 \cdot 8}$	Back pedalling down Classin's Bridge hill, inclination steep (1 in $10\frac{1}{2}$), surface rough; calm.

In order to appreciate the foregoing results, it will be well to compare them with the annexed table of the foot-pounds of energy expended per minute when working with certain fractions of a horse-power.

TABLE III.

Foot-pounds per Minute.	Equivalent Horsepower.	Foot-pounds per Minute.	Equivalent Horsepower.
11,000	$\frac{1}{3}$	3,000	$\frac{1}{11}$
8,250	$\frac{1}{4}$	2,750	$\frac{1}{12}$
6,600	$\frac{1}{5}$	2,538	$\frac{1}{13}$
5,500	$\frac{1}{6}$	2,357	$\frac{1}{14}$
4,714	$\frac{1}{7}$	2,200	$\frac{1}{15}$
4,125	$\frac{1}{8}$	2,062	$\frac{1}{16}$
3,667	$\frac{1}{9}$	1,941	$\frac{1}{17}$
3,300	$\frac{1}{10}$	1,833	$\frac{1}{18}$

It thus appears that the power exerted in several of the experiments (see experiments 19, 22, 28, 31, 35) amounted to between a quarter and a third of a horse-

power,* while the average furnished by all the experiments on nearly level ground —which we believe to be close to the average in ordinary road riding—amounts to between a seventh and a sixth of a horse-power. This is very sensibly more than the work which the muscles of a man seem capable of effecting in other applications of them. Thus in rowing, or in raising one's own weight, which are supposed to be two of the best ways of employing the muscles, the power which a man can exert for any continuance does not seem to reach much beyond the eighth of a horse-power. This in part accounts for the extraordinary feats which are daily being performed on bicycles, but it does not appear to give the whole account of the matter, for which we must look to physiology and psychology as well as to mechanics.

In fact the real comparison to be made is not so much a comparison of the feats accomplished with the energy expended as with the fatigue incurred. And this in riding a bicycle is small, not only from the mechanical efficiency which the foregoing experiments show the machine to possess but also for other reasons. Part of these are physiological. The rider is seated on the machine, and thus relieved from what is the chief source of fatigue in walking, the weight of his own body on his limbs. He is in the posture best adapted to the healthy play of the vital organs in the chest, and the constant slight movement of the muscles of the trunk contributes to this healthy play. Again, while the arms perform some of the work,† the principal part is relegated to the most powerful muscles of the body, those of the leg. It is also material to observe that these limbs are left very unusually free in their movements, and that the choice of what length of stroke he will employ, what force he will exert, and at what speed he will move his limbs, are left to the rider, who can adjust these details to be what best suit his own body. How much depends on these adaptations will be appreciated by any person who has ridden far with a saddle too low for him. The fatigue then experienced is sometimes accounted for by the supposition that the greatest pressure is exerted when the leg is nearly straight, and that the rider loses this most valuable part of the stroke; but all our experiments concur in showing that this is not the case (see Fig. 4, Pl. 40, and Fig. 8, Pl. 41) and that on the contrary, the greatest force is exerted almost exactly at the middle of the stroke. The reason seems rather to be that unless the knee is periodically straightened, the tendons, nerves, or blood-vessels which pass it are subjected without intermission to some restraint which incommodes them.

But besides the mechanical and the physiological elements, there is a third— an emotional element. This is the exhilaration felt in riding the bicycle, which

* This is the maximum attained in our experiments, which were limited by the range of the spring of the indicating apparatus; but in actual riding this maximum is often largely exceeded for a short time, as in spurting up a short stiff hill, and on other like occasions.

† The contribution made by the arms when pulling on the handles often seems to the rider out of proportion to the force they exert. Perhaps in such cases their chief office is to stiffen the trunk, and so give firm points of attachment to the upper ends of the great muscles of the legs.

in addition to that caused by the scenery passed through and other collateral circumstances, arises also from the mere exercise, and with most riders is of somewhat the same kind, but greater and more lasting than that experienced in riding on horseback.

It is obvious to remark, that our experiments seem to show that an economy may be effected in workshops where human muscular power is employed, wherever it is possible to apply it in the same way as on the bicycle, and with the adjustments which the bycycle rider has at his disposal. It is plain from the experience of bicycle riders that most work can be done with a given expenditure of fatigue, when the pressure against which the feet move is much less than the whole weight of the body.

Some information is given by plotting down on diagrams the results of all the experiments made on nearly level ground. This is done in Figures 9 and 10, Pl. 41, in which the points marked with a cross are those furnished by the experiments made in winter with the indicator apparatus attached to the top of the lever. Those representing the experiments made in summer, with the apparatus attached to the treadle, are surrounded by a circle. The scattered position of the points on these diagrams is, of course, owing to the great variety of conditions under which the observations were made—the state of the road, the wind, and the inclination (although always slight), having been very different.

Nevertheless the curves drawn through the midst of these scattered points may be taken fairly to represent the average expenditure of energy in ordinary flat road riding to attain speeds of from six to twelve miles an hour ; Figure 9, Pl. 41 furnishing the energy which must be expended per mile, and Figure 10, Pl. 41 the energy per minute, or, in other words, the power which must be exerted. Both of these rise rapidly with increasing speeds, and show that the lower speeds are much the most economical.

It is of interest to inquire what is practically the most economical speed to adopt. This is found in practice to be the speed at which the machine will travel when the rider after lifting the rising leg does a little more than allow its weight to act on the descending pedal. Sauntering in this way is scarcely felt to be work at all, and is often the pace which is best suited to relieve the fatigues of sedentary occupations. This under the conditions of our experiments has been found to furnish a speed of nearly six miles an hour on an ordinary road without wind, and this experience agrees well with Figure 9, for taking the stroke as ten inches and the weight of the leg from the knee down, along with half the weight of the upper leg, to be seventeen pounds, we shall have fifteen foot-pounds of work done each stroke, or thirty each revolution of the wheel. This would assign 11,500 foot-pounds to the mile, which if we venture to extend the curve in Figure 9, Pl. 41 backwards a very little, will bring it to a point which shows the corresponding speed to be five and three-quarter miles per hour.

This great efficiency of velocipedes when ridden slowly suggests that machines specially adapted to be ridden with the least possible effort at such low speeds as from four to six miles an hour, would be found useful for many purposes. A step in this direction has already been taken by the introduction of the excellent little "Facile" bicycle, with driving wheels sometimes as small as thirty-eight inches. And more would probably result from making machines of the tricycle class with driving wheels of from twenty-five to thirty inches diameter, for going to one's office in all weather, for shopping, for carrying parcels, for gently sauntering in the open air, for carrying invalids or children, and for many other useful purposes, to which velocipedes have as yet been little applied.

The machine with which the experiments in this paper were made, was that known, as the "Xtraordinary Challenge," 1880 pattern, roller bearings to a front wheel of fifty-two inches, and cones to the hind wheel. The height of the rider is five feet eleven and a half inches; length of leg, inside measure, thirty-six inches; length of stroke, nine three quarter inches. The weight of the rider, ten and a half stones; weight of machine sixty pounds. Hence the total weight of rider and machine was 207 pounds. To adapt our results to a rider, whose weight along with that of his machine is more or less than this, all the energies recorded in Tables I. and II., would, of course, have to be altered in proportion to the change of weight. Thus, with a rider whose weight is thirteen and a half stones, the sauntering pace above spoken of was found to be nearer five than six miles.

ADDENDUM.

Since the foregoing pages were written we have constructed a chronograph, as suggested on page 308, and have been able to resume the investigation by the kinetic method.

Our chronograph consists of a heavy pendulum to the rod of which a pencil is attached a few inches from the fulcrum. Behind the pendulum a vertical board is placed, mounted so that an assistant can by a winch make it travel upwards while the pendulum is swinging. To this board strips of paper, about five feet in length are fastened by drawing pins, and on this paper the pencil attached to the pendulum traces a wavy line in the form of a rough curve of sines. It only remained to have another pencil mounted on a trigger to produce dots at the will of the observer, and the position of these dots in relation to the curve of sines, gives with sufficient precision the times at which the dots are produced. The observations were made as follows:—One of us rode the bicycle, getting up a speed of from fourteen to sixteen miles an hour, then took his feet off the treadles and ran the machine without propelling it, till the speed fell to about four miles an hour. Meanwhile the other manipulated the trigger of the chronograph, and thus recorded the instants at which one treadle in successive revolutions reached its

lowest position. From twelve to twenty such dots were produced in each experiment.

From the record so produced a curve was plotted down on millimetric paper, giving the relation between the times (in swings of the chronograph pendulum), at which each revolution was completed, and the distances (in circumferences of the wheel) traversed by the bicycle.

A straight ruler being placed to touch this curve at any point enabled us to read off on the millimetric paper the tangent of its inclination, which was the velocity of the bicycle at the corresponding point of its journey. In this way the velocities at the end of each five revolutions of the wheel were determined, and plotted down in a second diagram which gave the relation between v the velocity, and s the distance traversed. This second diagram proved to be nearly a straight line, the deviations being within the limits of errors of observation; and the tangent of its inclination being read off on the millimetric paper furnished the value of $\frac{dv}{ds}$, which is the basis of the calculation which has next to be made. We made twenty-one experiments each of which had to be reduced in this way.

The resulting values of $\frac{dv}{ds}$ are as follows :—

TABLE III.

—	In Arbitrary Measure.	In Kinetic Measure.	—
A.—On level path with light wind.	$\frac{dv}{ds}=\cdot06$	$=\cdot045$	Average of five experiments.
B.—On level path against light wind.	$\frac{dv}{ds}=\cdot12$	$=\cdot091$	Average of three experiments.
C.—On level path without wind.	$\frac{dv}{ds}=\cdot078$	$=\cdot059$	Average of seven experiments.
D.—On an ordinary good level road without wind.	$\frac{dv}{ds}=\cdot085$	$=\cdot064$	Average of six experiments.

We have to deduce from these the energy per mile which would maintain any of the several velocities which the bicycle passed through. This is effected by the formula

$$\frac{de}{ds}=mv\frac{dv}{ds} \quad\text{.................}(1)$$

in which we must use some systematic set of kinetic measures. The most con-

venient for such mechanical problems are the measures based on the second as unit of time, the metre as unit of length, and the kilogram as unit of mass. These give one metre per second as the unit of velocity, and a Hyper-hectogrammetre as the unit of energy. The Hyper-hectogrammetre means the work done in pushing against a force of one Hyper-hectogram through a metre, and a Hyper-hectogram, which is the unit of force, is the weight of a hectogram increased in the proportion of 10 : g (*i.e.*, increased about 2 per cent.), g being gravity at the place of observation.

The second column of Table III., gives the values of $\frac{de}{ds}$ using the swing of the pendulum of the chronograph as unit of time, and the next column gives the equivalent values when a second is used as unit of time, the swing of the pendulum having been determined by independent experiments to be equal to 1·32 seconds. It is these latter values that are to be used in formula (1); m, in the same formula $=$ 207 pounds or 94 kilograms (see p. 314); v is the velocity in metres per second.

$$\text{Hence } \frac{de}{ds}\left(\text{in } \frac{\text{Hyper-hectogrammetres}}{\text{per metre}}\right) = 94 \times v \left(\text{in } \frac{\text{metres}}{\text{per second}}\right) \times \frac{dv}{ds}$$

(where for $\frac{dv}{ds}$ we are to use one of the values furnished by the third column of Table III.)

$$\text{Now a } \frac{\text{Hyper-hectogrammetre}}{\text{per metre}} = \frac{\cdot 74 \text{ of a foot-pound}}{\text{per metre}} = 1609 \times \frac{\cdot 74 \text{ of a foot-pound}}{\text{per mile}} = 1191 \ \frac{\text{foot-pounds}}{\text{per mile}}.$$

$$\text{And again } \frac{\text{a metre}}{\text{per second}} = \frac{3600}{1609} \ \frac{\text{miles}}{\text{per hour}}.$$

$$\text{Hence } \frac{\left(\frac{de}{ds} \text{ in } \frac{\text{foot-pounds}}{\text{per mile}}\right)}{1191} = 94 \times \frac{1609}{3600} \left(v \text{ in } \frac{\text{miles}}{\text{per hour}}\right) \times \frac{dv}{ds},$$

$$\text{Or } \left(\frac{de}{ds} \text{ in } \frac{\text{foot-pounds}}{\text{per mile}}\right) = 50037 \times \left(v \text{ in } \frac{\text{miles}}{\text{per hour}}\right) \times \frac{dv}{ds} \quad . \quad . \quad . \quad . \quad (3).$$

Hence, introducing the values of $\frac{dv}{ds}$ from Table III., we find—

TABLE IV.

No. of Experiment.	The Energy per Mile.	Observations.
32 to 36	$=2252 \times v$	On level footpath, in the direction of light wind.
37 to 39	$=4553 \times v$	On level footpath, against a light wind.
40 to 46	$=2952 \times v$	On the footpath, without wind.
47 to 52	$=3202 \times v$	On a good level road, without wind.

the energy being measured in foot-pounds, and v, the velocity, in miles per hour.

To compare these results with those furnished by the indicator diagrams, it will be convenient to compute from Table IV. the energy per mile, the energy per minute, and the coefficient of resistances at a velocity of nine miles per hour, which was the average speed in the experiments recorded in Tables I. and II. We thus obtain results in the same form as in Tables I. and II.

TABLE V.

Results of the Kinetic Experiments for a velocity of nine miles an hour.

No. of Experiment.	Energy per Mile.	Energy per Minute.	Velocity.	Coefficient of Resistances.	Observations.
32 to 36	20,268	3,040	9	$\frac{1}{34}$	On level footpath, in the direction of a light wind.
37 to 39	40,977	6,146	9	$\frac{1}{27}$	On level footpath, against light wind.
40 to 46	26,568	3,985	9	$\frac{1}{41}$	On level footpath, without wind.
47 to 52	28,818	4,323	9	$\frac{1}{38}$	On good level road, without wind.

These results are in substantial agreement with those of Tables I. and II., though obtained by a wholly different method of observation. The problem has thus been worked out in three distinct ways which confirm each other.

Fig. 1

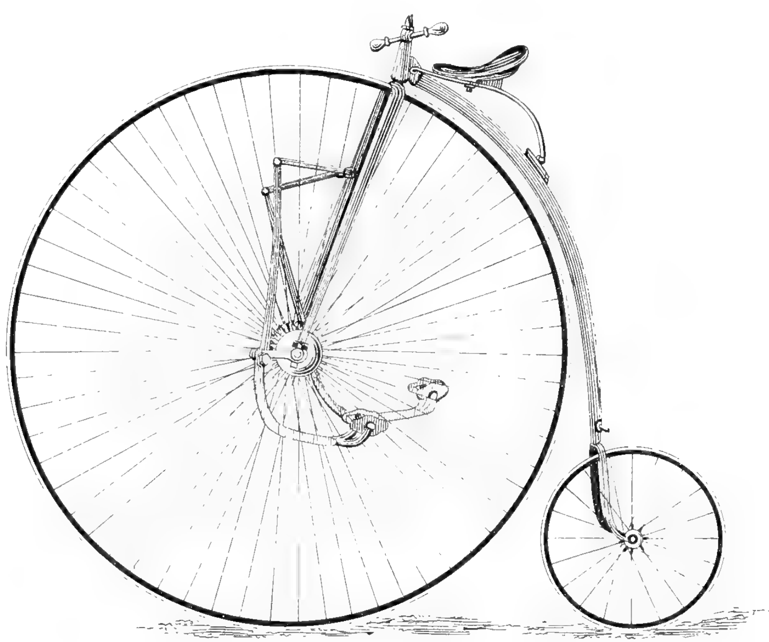

Fig. 2.

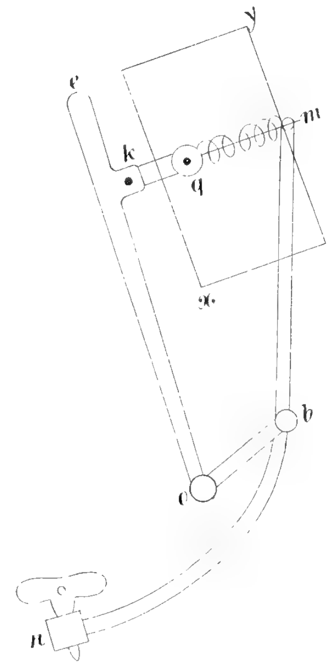

Fig. 3.

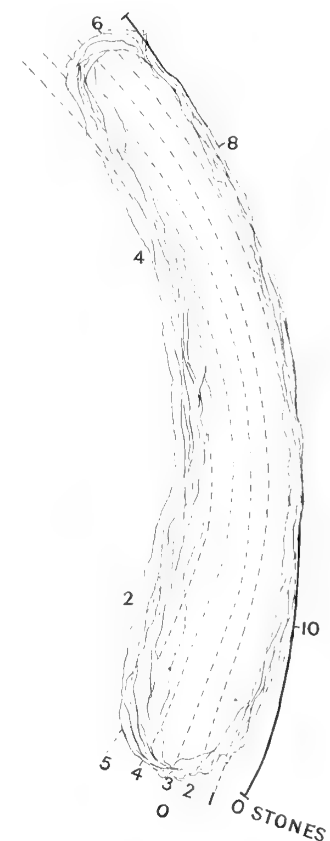

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Fig. 4.

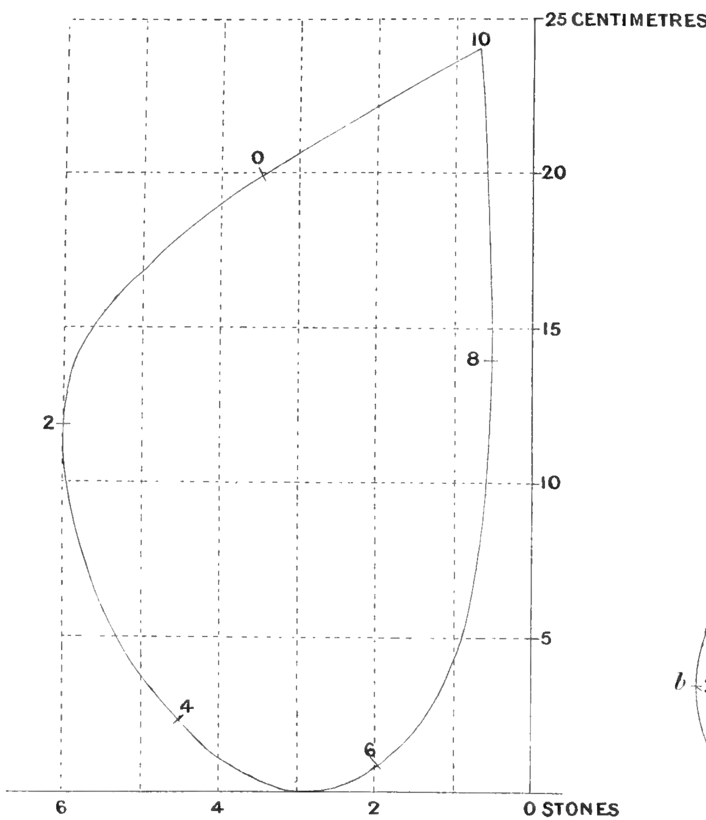
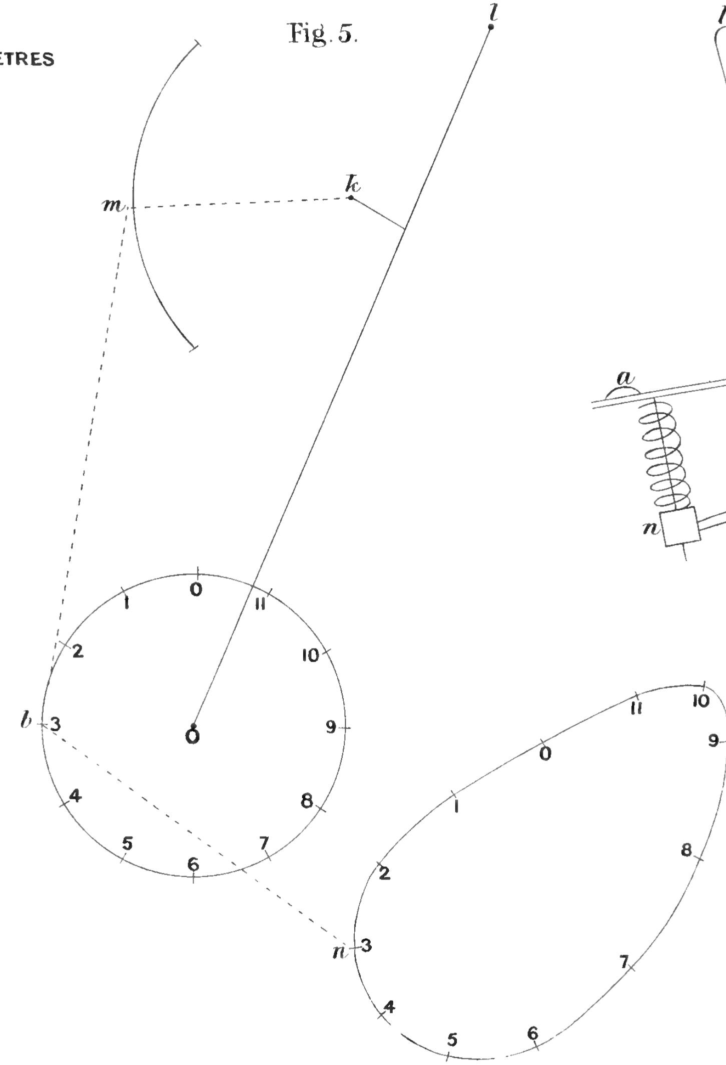


Fig. 5.



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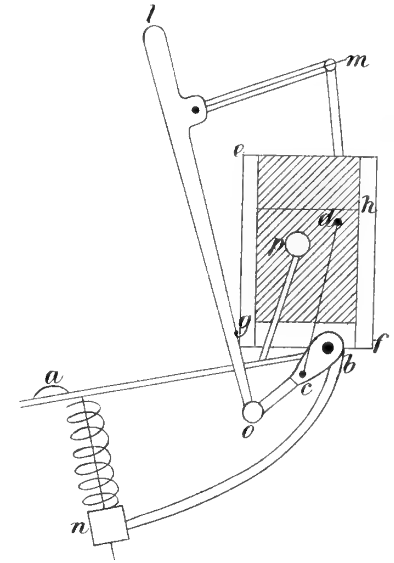

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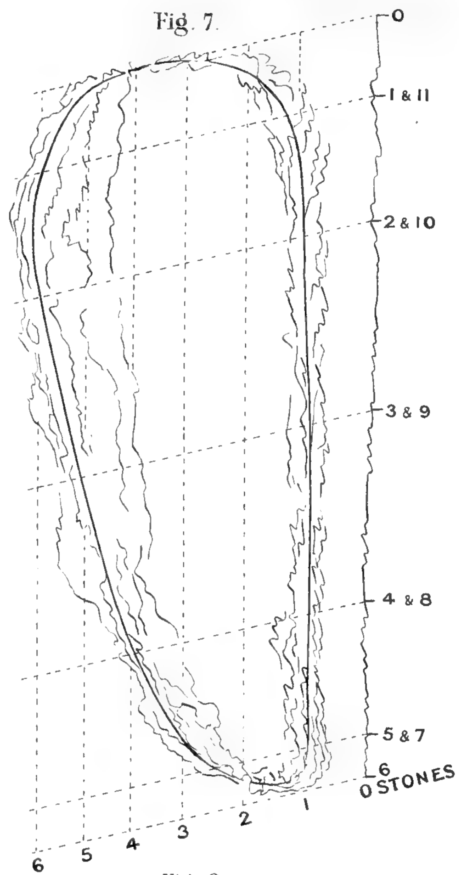


Fig. 8.

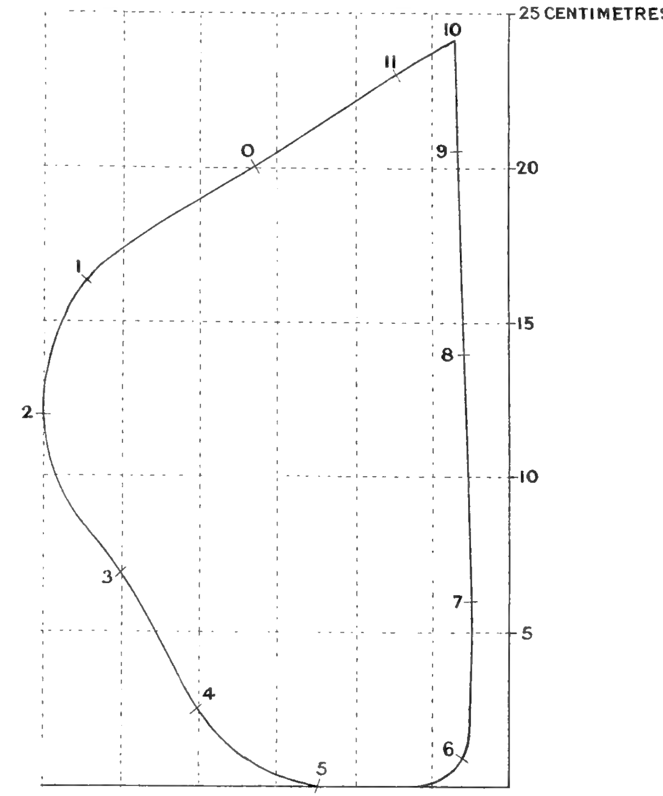


Fig. 9

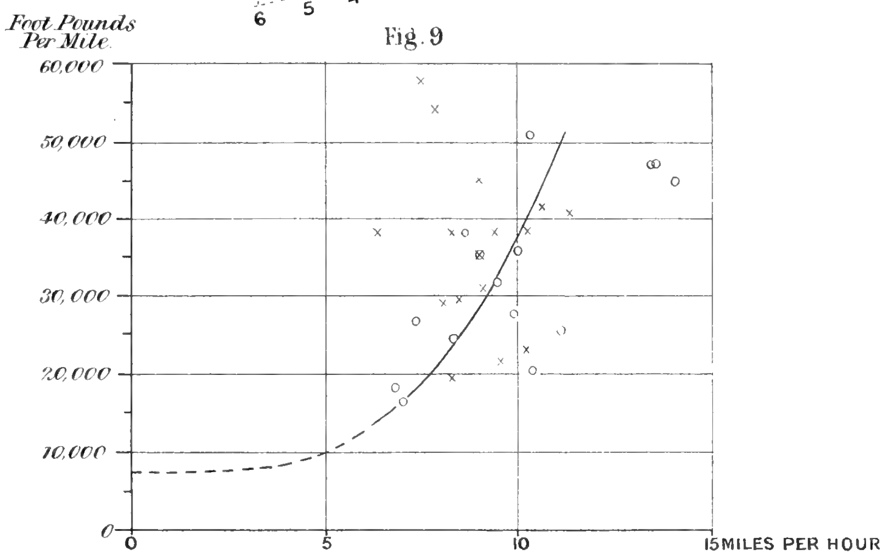
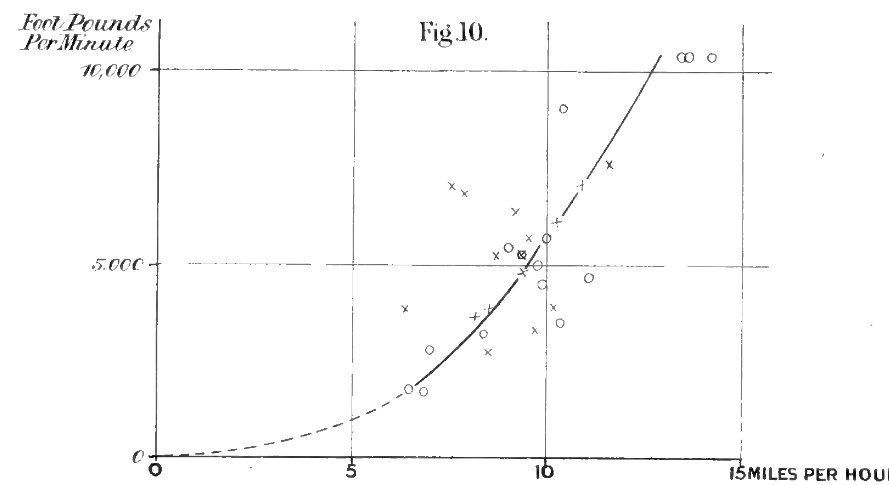


Fig. 10.



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[JANUARY, 1883.]

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XXIII.—ON ELECTROMAGNETIC EFFECTS DUE TO THE MOTION OF THE EARTH.

By Geo. Fras. FitzGerald, M.A., F.T.C.D., Erasmus Smith's Professor of Experimental Science in the University of Dublin.

[Read May 5th, 1882.]

Professor Rowland has shown experimentally that a quantity of electricity moving acts like an electric current. This had been assumed by many physicists. It follows that two quantities of electricity moving in the same direction and with the velocity of light, would have no action on one another; their electrostatic action being balanced by an equal and opposite electrokinetic action. As it is very unlikely that anything depends on absolute motion, the motion here spoken of must be with respect to something, and this something can hardly be any other thing than what is known as the ether in space.

All electromagnetic measurements are made on the surface of the earth, which is moving in a threefold way through space. The earth is rotating on its axis, and its equatorial surface is moving at the rate of $4{\cdot}65 \times 10^4$ c.m. per sec. It is moving round the sun at the rate of $2{\cdot}96 \times 10^6$ c.m. per sec. It is moving with the whole solar system through space, at about the same rate.

Professor Stokes has shown that aberration would be the same, whether the ether near the earth be carried along with it or no. Fizeau's experiments, however, show that matter does not carry the ether along with it except to an extent depending on the refractive index of the matter. It would follow that no appreciable part of the ether in the air moves with the earth.

All electrostatic measurements should show a twofold periodicity; one diurnal, the other annual. The velocity of the electricity through the ether is different at different times of the day, owing to its motion due to the rotation of the earth being sometimes added, and sometimes subtracted, from its other motions. It is different at different times of the year, owing to the velocity of the earth round the sun being sometimes added to and sometimes subtracted from the component along the ecliptic of the solar system's velocity in space. The velocity of light is 3×10^{10} c.m. per sec., and the daily variation of velocity would consequently change electrostatic attractions by the $3{\cdot}1 \times 10^{-6}$ of their amount, and the annual variation would change them by about the $1{\cdot}5 \times 10^{-4}$ of their amount. These quantities do not seem beyond the possibility of observation with specially constructed instruments.

It has been supposed that in conformity with these electrostatic actions, there

would be a force on a magnet, due to an electrified body moving along with the magnet. It appears to me that this is not the case. For consider the action of a current on a quantity of electricity, when both are carried through space. When a current producing an electromagnetic potential, whose components are F, G, H, moves with a velocity of translation whose components are $\dot{x}$, $\dot{y}$, $\dot{z}$, the components of electromotive intensity are

$$P_1 = -\frac{dF}{dt} = -\left(\frac{dF}{dx}\dot{x} + \frac{dF}{dy}\dot{y} + \frac{dF}{dz}\dot{z}\right)$$
$$Q_1 = -\frac{dG}{dt} = -\left(\frac{dG}{dx}\dot{x} + \frac{dG}{dy}\dot{y} + \frac{dG}{dz}\dot{z}\right)$$
$$R_1 = -\frac{dH}{dt} = -\left(\frac{dH}{dx}\dot{x} + \frac{dH}{dy}\dot{y} + \frac{dH}{dz}\dot{z}\right)$$

If a point move with a velocity whose components are $\dot{\xi}$, $\dot{\eta}$, $\dot{\zeta}$, then the component of electromotive intensity at it are $P = c\dot{\eta} - b\dot{\zeta}$, &c., where a, b, c, are the components of magnetic induction at the point. Putting in for a, b, c, we get

$$P_2 = \dot{\eta}\left(\frac{dG}{d\xi} - \frac{dF}{d\eta}\right) - \dot{\zeta}\left(\frac{dF}{d\zeta} - \frac{dH}{d\xi}\right)$$
$$= \dot{\xi}\frac{dF}{d\xi} + \dot{\eta}\frac{dG}{d\xi} + \dot{\zeta}\frac{dH}{d\xi} - \left(\dot{\xi}\frac{dF}{d\xi} + \dot{\eta}\frac{dF}{d\eta} + \dot{\zeta}\frac{dF}{d\zeta}\right)$$
$$= \frac{d}{d\xi}(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}) + \dot{\xi}\frac{dF}{dx} + \dot{\eta}\frac{dF}{dy} + \dot{\zeta}\frac{dF}{dz}$$
$$Q_2 = \frac{d}{d\eta}(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}) + \dot{\xi}\frac{dG}{dx} + \dot{\eta}\frac{dG}{dy} + \dot{\zeta}\frac{dG}{dz}$$
$$R_2 = \frac{d}{d\zeta}(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}) + \dot{\xi}\frac{dH}{dx} + \dot{\eta}\frac{dH}{dy} + \dot{\zeta}\frac{dH}{dz}$$

Hence the whole electromotive intensity at the point has components :—

$$P = \frac{d}{d\xi}\left(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}\right) + \frac{dF}{dx}(\dot{\xi} - \dot{x}) + \frac{dF}{dy}(\dot{\eta} - \dot{y}) + \frac{dH}{dz}(\dot{\zeta} - \dot{z})$$
$$Q = \frac{d}{d\eta}\left(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}\right) + \frac{dG}{dx}(\dot{\xi} - \dot{x}) + \frac{dG}{dy}(\dot{\eta} - \dot{y}) + \frac{dG}{dz}(\dot{\zeta} - \dot{z})$$
$$R = \frac{d}{d\zeta}\left(F\dot{\xi} + G\dot{\eta} + H\dot{\zeta}\right) + \frac{dH}{dx}(\dot{\xi} - \dot{x}) + \frac{dH}{dy}(\dot{\eta} - \dot{y}) + \frac{dH}{dz}(\dot{\zeta} - \dot{z}).$$

If the two move with the same velocity so that $\dot{\xi} = \dot{x}, \dot{\eta} = \dot{y}$ and $\dot{\zeta} = \dot{z}$ the components become

$$P = \frac{d}{d\xi}(F\dot{x} + G\dot{y} + H\dot{z})$$
$$Q = \frac{d}{d\eta}(F\dot{x} + G\dot{y} + H\dot{z})$$
$$R = \frac{d}{d\zeta}(F\dot{x} + G\dot{y} + H\dot{z}).$$

Now as—

$$F = \mu \iiint \frac{u}{r} dx\, dy\, dz$$
$$G = \mu \iiint \frac{v}{r} dx\, dy\, dz$$
$$H = \mu \iiint \frac{w}{r} dx\, dy\, dz$$

when $u\ v\ w$ are the components of the current, and

$$r^2=(\xi-x)^2+(\eta-y)^2+(\zeta-z)^2$$

if we call

$$u\dot{x}+v\dot{y}+w\dot{z}=\Theta$$

and—

$$\iiint\frac{\mu\Theta}{r}\,dx\,dy\,dz=\Psi$$

we get—

$$P=\frac{d\Psi}{d\xi}$$

$$Q=\frac{d\Psi}{d\eta}$$

$$R=\frac{d\Psi}{d\zeta}$$

This result may be more rapidly obtained by using the quaternion notation thus :—

The electromotive intensity due to the current moving is

$$\mathfrak{E}_1=-\frac{d\mathfrak{A}}{dt}=-\left(\dot{x}\frac{d\mathfrak{A}}{du}+\dot{y}\frac{d\mathfrak{A}}{dy}+\dot{z}\frac{d\mathfrak{A}}{d_z}\right)=-(\mathrm{S}\dot{\rho}\Delta)\,\mathfrak{A}$$

using—

$$\mathrm{S}\dot{\rho}\Delta=\dot{x}\frac{d}{dx}+\dot{y}\frac{d}{dy}+\dot{z}\frac{d}{dz}\text{ as an operator.}$$

Similarly the electromotive intensity at the moving point is—

$$\mathfrak{E}_2=\mathrm{V}\dot{\rho}'\mathfrak{B}\text{ and }\mathfrak{B}=\mathrm{V}\Delta'\mathfrak{A}$$

where—

$$\rho'=\xi i+\eta j+\zeta k\text{ and }\Delta'=i\frac{d}{d\xi}+j\frac{d}{d\eta}+k\frac{d}{d\zeta}$$

Hence—

$$\mathfrak{E}_2=\mathrm{V}\dot{\rho}'(\mathrm{V}\Delta'\mathfrak{A})=\Delta'(\mathrm{S}\dot{\rho}'\mathfrak{A})-(\mathrm{S}\dot{\rho}'\Delta')\mathfrak{A}$$

also $\Delta'=-\Delta$ hence—

$$\mathfrak{E}=\mathfrak{E}_1+\mathfrak{E}_2=\Delta(\mathrm{S}\dot{\rho}'\mathfrak{A})+\big(\mathrm{S}(\dot{\rho}'-\dot{\rho})\Delta\big)\mathfrak{A}$$

so that if $\dot{\rho}'=\dot{\rho}$

$$\mathfrak{E}=\Delta(\mathrm{S}\dot{\rho}\mathfrak{A})=\Delta(\Psi)$$

where

$$\Psi=\mathrm{S}\dot{\rho}\mathfrak{A}=\iiint\mu\frac{\mathrm{S}(\dot{\rho}\mathfrak{C})}{\mathrm{T}r}\,dx\,dy\,dz$$

and consequently

$$\Theta=\mathrm{S}(\dot{\rho}\mathfrak{C})$$

Expressed thus it is evident that the resulting electromotive force round a closed circuit would vanish, and that the electromotive intensity at each point of space is the same as that due to electricity of density $\mu\Theta$ at each element of current. The total quantity of electricity required for this is zero, in the case of a closed circuit, for

$$\iiint(\mathrm{S}\dot{\rho}\mathfrak{C})\,dx\,dy\,dz=\iiint u\,dx\,dy\,dz=\iiint v\,dx\,dy\,dz=\iiint w\,dx\,dy\,dz=0$$

when the integration is extended round closed circuits. From this it is evident that an electric current in a conductor would have no electromotive intensity on a point outside it, and moving with its own velocity; for, just as electricity enclosed in the conductor would have no effect outside, similarly the current in the conductor would induce on its surface exactly such a charge as would neutralise the action due to the motion of the current on all points moving with the same velocity.

Hence the complete value for the electromotive intensity at a point, due to a current in a conductor, when both the point and conductor are moving, is

$$\mathfrak{E}=(S(\dot{\rho}'-\dot{\rho})\Delta)\mathfrak{A}$$

i.e., its components are

$$P=(\dot{\xi}-\dot{x})\frac{dF}{dx}+(\dot{\eta}-\dot{y})\frac{dF}{dy}+(\dot{\zeta}-\dot{z})\frac{dF}{dz}$$

$$Q=(\dot{\xi}-\dot{x})\frac{dG}{dx}+(\dot{\eta}-\dot{y})\frac{dG}{dy}+(\dot{\zeta}-\dot{z})\frac{dG}{dz}$$

$$R=(\dot{\xi}-\dot{x})\frac{dH}{dx}+(\dot{\eta}-\dot{y})\frac{dH}{dy}+(\dot{\zeta}-\dot{z})\frac{dH}{dz}$$

The mechanical force at the point, as given by Maxwell, is

$$\mathfrak{F}=V\mathfrak{B}\mathfrak{C}-e\Delta\Psi,$$

i.e., its components are

$$X=cv-bw-e\frac{d\Psi}{dx}$$

$$Y=aw-cu-e\frac{d\Psi}{dy}$$

$$Z=bu-av-e\frac{d\Psi}{dz}$$

The electromotive intensity at the point, as given by Maxwell, is

$$\mathfrak{E}=V\mathfrak{B}\dot{\rho}-\frac{d\mathfrak{A}}{dt}-\Delta\Psi$$

i.e., its components are

$$P=c\dot{y}-b\dot{z}-\frac{dF}{dt}-\frac{d\Psi}{dx}$$

$$Q=a\dot{z}-c\dot{x}-\frac{dG}{dt}-\frac{d\Psi}{dy}$$

$$R=b\dot{x}-a\dot{y}-\frac{dH}{dt}-\frac{d\Psi}{dz}$$

Now there does not seem any reason why the mechanical force should not be written

$$\mathfrak{F}=V\mathfrak{B}\mathfrak{C}+e\mathfrak{E}$$

i.e., its components are

$$X=cv-bw+eP$$
$$Y=aw-cu+eQ$$
$$Z=vu-av+eR$$

for is it not the meaning of the electromotive intensity, that the mechanical force due to it on a quantity of electricity, e, is $e\,\mathfrak{E}$? Although in his enumeration of the equations of the electromagnetic field, Maxwell gives the equations as at first cited, yet in § 631, where he is deducing the general expression for the electrostatic energy of the field, he practically assumes that the second expression I have given is the true one. Hence the mechanical force at a point moving with a velocity $\dot{\rho}$ and carrying a current $\mathfrak{C}$, and charged with a quantity of electricity e, is

$$\mathfrak{F}=V\mathfrak{B}\mathfrak{C}+eV\mathfrak{B}\dot{\rho}-e\frac{d\mathfrak{A}}{dt}-e\Delta\Psi$$

i.e., its components are

$$X = cv - bw + e(c\dot{y} - b\dot{z}) - e\frac{dF}{dt} - e\frac{d\Psi}{dx}$$

$$Y = aw - cu + e(a\dot{z} - c\dot{x}) - e\frac{dG}{dt} - e\frac{d\Psi}{dy}$$

$$Z = bu - av + e(b\dot{x} - a\dot{y}) - e\frac{dH}{dt} - e\frac{d\Psi}{dz}$$

Now when there is no conduction current at the point $u=v=w=0$. For it would evidently be improper to include e twice over, first as a quantity of electricity, and secondly as a current. In the equations as I give them, the effect of the motion of e is included under $e\,\mathrm{V}\,\mathfrak{B}\dot{\rho}$, *i.e.*, in the components, as $e\,(c\dot{y} - b\dot{z})$, &c. Hence we get that if there be no conduction current at the point but only this convection current, the mechanical force is completely represented by

$$\mathfrak{F} = e\mathfrak{E}$$

i.e., its components are

$$X = eP$$

$$Y = eQ$$

$$Z = eR$$

and that there will consequently be no mechanical force at points where the electromotive intensity vanishes.

It has just been shown that the electromotive intensity vanishes at a point outside a magnet, moving with the same velocity as the magnet, and I hence conclude that there would be no force on an electrified body moving with the magnet.

If we consider the electrified body as acting on the magnet, we are led to a similar result. In this case the moving electricity has an electromotive intensity

$$\mathfrak{E} = \mu \iiiiiint \frac{e\dot{\rho}}{\mathrm{T}r} \cdot dx\,dy\,dz\,d\xi\,d\eta\,d\zeta$$

or as

$$\Psi = \iiint \frac{e}{\mathrm{T}r} dx\,dy\,dz$$

$$\mathfrak{E} = \mu \iiint \Psi\dot{\rho}\,d\xi\,d\eta\,d\zeta$$

i.e., its components are,

$$P = \mu \iiint \Psi\dot{x}\,d\xi\,d\eta\,d\zeta$$

$$Q = \mu \iiint \Psi\dot{y}\,d\xi\,d\eta\,d\zeta$$

$$R = \mu \iiint \Psi\dot{z}\,d\xi\,d\eta\,d\zeta$$

Hence if Ψ be constant all over any space, the magnetic force vanishes throughout that space. Now Ψ must be constant all over the inside of a magnet. Hence we see that the electricity induced on the outside of a magnet by externa electricity moving with it, exactly neutralises both the electrostatic and electromagnetic actions of the external electricity on the inside of the magnet. We thus see that the magnetism inside the magnet, and the convection current outside are related

* It may be worth while remarking that the actions of convection currents which, with Maxwell's equations, seem to need an additional assumption, come out as obvious results of the equation as here given.

to one another exactly like a quantity of electricity inside and outside a closed conductor, each induces on the conductor exactly such a charge as to neutralise its action on the other. The outstanding action on the conductor is exactly the same as if there were no internal charge at all. Hence it seems that the action on a magnet would be independent of its magnetization, and would be only that feeble force due to the electromagnetic action of the superficial induced charge. It is useless then to expect to obtain measurable forces by the action of electricity on magnets, when both are carried along by the earth.

It seems hardly necessary to point out that the action of two conduction currents upon one another is unaffected by their common motion, as equal quantities of positive and negative electricities are present at each point, and there is consequently no convection action.

I have throughout this investigation left out of account, as too small to be worth including, the self-induction of the displacement currents produced in the dielectrics. It is, however, very desirable that their action should be completely investigated, in order to see whether they can produce measurable effects, for instance in the case of powerful electromagnets.

XXIV.—ON THE POSSIBILITY OF ORIGINATING WAVE DISTURBANCES IN THE ETHER BY MEANS OF ELECTRIC FORCES:—CORRECTIONS AND ADDITIONS.

By Geo. Fras. FitzGerald, M.A., F.T.C.D.

[Read May 5th, 1882.]

Since publishing Part II. of these papers (these Transactions *antea*, page 173), I have come across an investigation of the differential equation I there studied in Lord Rayleigh's "Theory of Sound," Vol. II., § 276. He assumes the solution to contain imaginary terms of the form e^{int}, just as I assumed it to contain real terms of the form $\cos nt$ and he obtains the same general form of solution as I do. To a simply periodic term, however, there corresponds in his solution a term of the form—

$$A\frac{\cos(nt-mr)}{r}$$

instead of the term I obtained,

$$A\frac{\cos nt \cos mr}{r}.$$

Taking Lord Rayleigh's form of solution would lead to the conclusion that a simply periodic current would originate wave disturbances such as light and not the stationary waves that my solution leads to.

I have not been able from purely mathematical considerations to determine which form of solution is preferable. Each is only a partial and not a general solution, and the form depends on the limiting conditions which are the same in both, when r is small and when it is infinite. When mr is small, the two forms are indistinguishable, and it is not easy to make experiments in which mr is not small, and I know of none that can help to decide between the forms. If we could make experiments where $\left(mr=\frac{\pi}{2}\right)$ we could easily distinguish between them, but as this would be at a distance of several miles from the varying current when the variations were as rapid as in the highest audible note, there does not seem much hope from experiments in this direction. Dr. Oliver Lodge has already tried to originate light by induced currents of a high order. It does not seem that this method of producing very rapidly varying currents would succeed beyond the third or fourth orders, for the induced currents of the higher orders tend more and more to become simply periodic, and after that there is only one induced current corresponding to each inducing one. It might, however, be possible to obtain sufficiently rapidly alternating currents by discharging condensers through circuits of small

resistance. The only experiments with which I am acquainted on the magnetic effects of such discharges seem to indicate a periodic law for the induction near the circuit.

In the theory of sound it is known that the disturbances are propagated outwards, and that the energy of the vibrating body is gradually transferred to the medium, and so we know which solution to employ. If a body be sounding in the centre of a closed sphere of the right size during the time that the sound takes to reach the surface of the sphere, the first form of solution holds; but as soon as the reflected wave combines with the direct one the second form is the right one. If the electro-magnetic action is analogous to this, it seems to follow that in infinite space where there is nothing to produce the reflected wave the first form of solution, in which all the energy is gradually transferred to the medium, is the right one to employ. Indeed it seems almost impossible without calling in the aid of some form of direct action at a distance to see how the stationary waves can be simultaneously originated throughout space.

If, however, as is generally assumed, a system of perfect conductors carrying currents be a conservation system they cannot be analogous to a system such as a sounding body in air, for if they were and the currents vary in intensity they would gradually transfer their energy to the ether. In my first paper on this subject I investigated it from this point of view. Assuming that the theory of direct action at a distance, and Maxwell's of action through a medium, lead to the same results I showed that electric currents could not originate wave disturbances such as light. From my subsequent paper it is however clear that the assumption that the two theories lead to the same results is only true to the same order of approximation as omitting the mutual induction of the displacement currents in the non-conducting medium. This is evident from the fact that the equations for calculating the vector potential on the theory of direct action at a distance could never make it vanish short of infinity while the equations founded on Maxwell's theory certainly lead to the conclusion that either the energy is gradually transferred to the medium or else that the vector potential vanishes at each of a series of distances given by an equation of the form $\cos mr = 0$. Hence these papers at least show that contrary to the ordinary assumption the two theories do not lead to the same results, and they point out a direction in which to investigate which theory is true. It seems further highly probable that the energy of varying currents is in part radiated into space and so lost to us. It seems further probable that, contrary to what I have stated in my first paper, the interactions between the molecules of matter and the ether are of the same character as the electromagnetic actions with which we are acquainted.

In conclusion I must apologize for having ventured to investigate these matters when I was so ignorant of what had already been done as to make mistakes requiring such serious corrections as are contained in this paper.

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ON THE

FOSSIL FISHES OF THE CARBONIFEROUS LIMESTONE SERIES

OF

GREAT BRITAIN.

BY

JAMES W. DAVIS, F.G.S.

PLATES XLII. TO LXV.

[FROM THE SCIENTIFIC TRANSACTIONS OF THE ROYAL DUBLIN SOCIETY. VOL. I. SER. II.]

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(Read May 15th, 1882.)

CONTENTS.

1. Explanatory Preface.

The observations and descriptions contained in the following pages have been based on material derived principally from the magnificent collection of the Earl of Enniskillen, at Florence Court, Ireland; a collection far transcending all others, not only in the extent and rarity of its contents, but in the number of unique specimens which it contains. Since the commencement of this memoir, the collection has been removed to the new Natural History Department of the British Museum at South Kensington, where it will, conjointly with the twin collection of the late Sir Philip de Malpas Grey Egerton, Bart., form an unrivalled exposition of the Ichthyic fauna of the past ages of the globe. It is fitting that the results of the unremitting labours of the two noble ichthyologists, pursued in happy unison during half a century, should find a home in the national collection.

The collections at the British Museum; the Museum of the Geological Society, Burlington House; the Museum at Bristol; the Dublin Museum; the Woodwardian Museum at Cambridge; the Museum of the Philosophical Society at York; the Museum at Clifton College, Bristol, and others, have been most kindly placed at my disposal, and, where necessary, specimens from those collections have been lent for illustration.

It is with great pleasure that I express my indebtedness to those gentlemen who have aided my researches, amongst whom I may name, I hope, without any invidious distinction, my friends Dr. Woodward and Mr. R. Etheredge, Dr. E. Perceval Wright, of Dublin; Prof. Hughes, of Cambridge; Prof. Sollas, of Bristol, and Dr. Grenfall, of Clifton College; Dr. Reed, of York, (who by his recent gifts of his

own and the late Mr. Wood's collections, to the York Museum, has set an example worthy of emulation), Mr. William Horne, of Leyburn, in Wensleydale, to whose rich private collection I have had free access. To Mr. Walter Keeping, at the Woodwardian Museum, and his son, Mr. W. Keeping, at York, I am obliged for kindly rendered attentions, and to Mr. W. Percy Sladen, my dear friend and near neighbour, for help not easily expressed in words—to many others my thanks are due and heartily tendered.

To Lord Enniskillen, without whose aid this memoir would have been well nigh impossible, I cannot sufficiently express my sense of obligation. His great and practical knowledge of the fossils in his collection; his intimate intercourse with that learned ichthyologist, the author of "Poissons Fossiles," and the knowledge his lordship possessed of the unpublished researches of M. Agassiz, have, in some departments, rendered my labour comparatively easy, whilst the genial and kindly friendship always exhibited has rendered my work at all times most agreeable.

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2. Classified Description of the Fossil Fishes.

Pisces.

It is proposed in the following descriptions to adopt the classification recently (1880) published by Dr. Albert C. L. G. Günther in his "Introductory Study of Fishes." The class Pisces is divided into four sub-classes, viz.:—

I.	Palæichthytes.		
II.	Teleostei	=	Teleostei (Huxley).
III.	Cyclostomata	=	Marsipobranchii (Huxley).
IV.	Leptocardii	=	Pharyngobranchii (Huxley).

The fishes of the Mountain Limestone formations belong exclusively to the first sub-class which is defined as follows by Dr. Günther.

I. Palæichthytes.

Heart with a contractile conus arteriosus; intestine with a spiral valve; optic nerves non-decussating, or only partially decussating; skeleton cartilaginous or osseous.

This sub-class is divided into two orders, viz.:—the *Chondropterygii* and the *Ganoidei.* The former being equivalent to the *Elasmobranchii* (Bonaparte) of Professor Huxley's classification, and including the sharks, rays, and chimeras. The latter embraces the orders *Ganoidei* and *Dipnoi* of Professor Huxley.

Order 1. Chondropterygii.

"Skeleton cartilaginous. Body with median and paired fins, the under pair

abdominal. Vertebral column generally heterocercal, the upper lobe of the caudal fin produced. Gills attached to the skin by the outer margin, with several intervening gill openings; rarely one external gill opening only. No gill cover. No air bladder. Two, three, or more series of valves in the conus arteriosus. Ova large and few in number, impregnated, and in some species developed, within an uterine cavity. Embryo with deciduous external gills. Males with intromittent organs attached to the ventral fins."—(*Günther.*)

This order is divided into two sub-orders: *Plagiostomata* and *Holocephala*; the first comprising the sharks and rays; the second, the chimeras.

Sub-order 1. PLAGIOSTOMATA.

"From five to seven gill openings. Skull with a suspensorium and the palatal apparatus detached. Teeth numerous."—(*Günther.*)

The *Plagiostomata* may be divided into two groups, the (A) *Selachoidei* or sharks, whose body is elongate, more or less cylindrical, gradually passing into the tail; gill openings lateral.

The (B) *Batoidei* or rays, in which the body is depressed, and surrounded by immensely developed pectoral fins, forming a broad flat disc. Caudal portion more or less rapidly contracted to form the tail. Gill openings, five in number, are always placed on the abdominal aspect of the fish.

The fish-remains found in the Mountain Limestone formations have hitherto not proved very numerous, nor have they been discovered in a great number of localities, considering the large area occupied by this group of rocks, its great vertical thickness, and the large extent to which it has been excavated for commercial purposes. The Limestone in the great majority of localities does not appear to contain any remains of fishes, and with the exception of the Armagh district and that of Bristol, other localities, including Wensleydale, Kendal, Derbyshire, and Oreton in Salop, have added few, either specimens or species, to enrich the knowledge of the ichthyic fauna of that ancient period.

The fish-remains hitherto found in the Carboniferous or Mountain Limestone, belong with few exceptions to the Plagiostomata—the sharks and rays—and consist of an almost endless variety of teeth, and a large number of spines. A very slight consideration of the anatomical constitution of an existing shark will give an idea of the difficulty attending the determination of the species of the several fossils, and still more of the almost utter impossibility of reconstructing, on a sufficiently certain and scientific basis, anything approaching a correct idea of the form and parts of the extinct fish. In existing sharks the whole framework of the body is frequently cartilaginous. The skull and mandible are well developed, but are entirely composed of cartilage; the pectoral and pelvic arches are the same; the vertebræ are in many fishes cartilaginous, in others a slight ring of bone is embedded in the

vertebræ and there is further modification in the direction of a completely osseous centrum. The teeth, the spines placed in front of the dorsal or pectoral fins or other parts of the body, and the dermal tubercles or shagreen, are the only parts of the fishes which are composed of an osseous or other hard substance which would be capable of resisting speedy decomposition after death. As might be naturally inferred, these are the only parts of the fishes of Carboniferous age which are found fossil ; even the vertebræ appear to have been entirely devoid of calcareous deposit and with the remaining cartilaginous portions of the fish have been decomposed and lost. The cartilaginous framework which held the teeth and spines together having decayed, these less destructible organs speedily became separated, and may have been carried considerable distances apart by currents or tides before they were eventually embedded. It is an extremely rare occurrence to find the various teeth, spines, and dermal tubercles, in such relationship that they can be identified as belonging to the same fish. Not only is this the case with the separated spines and teeth, but the greatest confusion may, and no doubt does to a large extent, exist in the determination of the many forms of teeth, and it may easily happen that the teeth which have lain side by side in the palate of one fish, may be considered by the ichthyologist as representing not only different species but present so marked differences in form as to lead to their being placed under separate genera. An interesting example of this kind, in which the two genera Cochliodus and Helodus, instituted by Professor Agassiz, though they had been found in several countries in Europe as well as in America, and for more than thirty years considered as separate genera, were ultimately found, by the fortunate discovery of a specimen with the teeth undisturbed, to be one and the same genus.* The organs on which modern classification is based :—the non-decussating optic nerves ; the muscular *conus arteriosus* with its varied rows of valvular openings ; and the spiral valve of the intestine, have no existence in a fossil state, and it is only by analogy that it can be reasoned that as in recent fishes it is found that certain functional relations exist between the soft and the hard parts of the fishes, so having procured the hard bony *disjecta membra* of the extinct fishes, and these exhibiting certain relationships with the recent forms, it may be inferred that the more perishable portions have also borne a similar relationship to those of recent forms.

The fishes of the Mountain Limestone, excepting Ganoids, are comprised in the sub-order Plagiostomata of Günther, which includes the sharks and rays, but excludes the chimeroid fishes, and for this reason the sub-order as defined by Dr. Günther is perhaps preferable to the Elasmobranchii of Professor Huxley in considering the fishes of Carboniferous age ; the Chimeræ being of Jurassic, Cretaceous, and Tertiary age, unless the bones described by Newberry in "The Geology of Ohio," Vol. I., page 307, as Rhynchodus should be proved to carry the origin of the group so far back as Carboniferous times.

*"Geological Survey of Illinois," Vol. II., pp. 88–89.

The Plagiostomatous fishes may be conveniently divided into six groups for the purposes of the present work, viz.:—

I. Hybodontidæ.—Type, Ctenacanthus.
II. Orodontidæ.—Type, Orodus.
III. Petalodontidæ.—Type, Petalodus.
IV. Cochliodontidæ.—Type, Cochliodus.
V. Psammodontidæ.—Type, Psammodus.
VI. Copodontidæ.—Type, Copodus.

The first group (Hybodontidæ) comprises the spines of Ctenacanthus and probably some others. From the great resemblance of Ctenacanthus with Hybodus it has been recognised by the late Sir P. Egerton and others as a Hybodont and arranged accordingly. The teeth of Hybodus are well known, many specimens having been discovered in the Lias of Lyme Regis, which have proved conclusively their connection with the spines. The teeth and spines of Ctenacanthus have not been so found, but judging from analogy it appears probable that the teeth of Cladodus may have been associated with the spines of Ctenacanthus. Except that the Cladodi are more formidable and that the coronal prominences are more prominent, they bear a close resemblance to the teeth of Hybodus.

The Orodontidæ comprise a group of teeth related to the existing Cestracionts, but in several essential respects differing from them, as will be stated more fully hereafter.

The Petalodontidæ will embrace the genera defined by Messrs. Newberry and Worthen in the synopsis of the Petalodont genera ("Geol. Survey, Illinois," Vol. II., p. 31) with the addition of some genera not included by those authors. This group has generally been considered by various authors as more or less associated with the family of Cestracionts, but, as will be seen, there are reasons why it should be removed from this association, and may be considered as possessing sufficiently distinct and characteristic features to render necessary the constitution of a separate family, as indicated by Messrs. Newberry and Worthen. The peculiar arrangement of teeth and their apparent relationship to Janassa of Münster also confirms this separation, and may indicate an evolutional passage between the sharks and the rays. The large and beautiful series of the teeth of the Petalorhynchus in the collection of the Earl of Enniskillen have rendered possible this generalization, and to Lord Enniskillen is due the credit of having suggested the relationship of the genus to Janassa.

The Cochliodontidæ embraces an interesting and most peculiar series of forms of dentition. In many respects it presents resemblances to the palates of the existing Cestracion, but it is difficult to conceive that the numerous teeth of Cestracion should be very closely related to the single enrolled tooth of some Cochliodonts. The point of resemblance consists in the cartilaginous jaw being enveloped in each

instance by a pavement-like surface of crushing teeth. As will be seen, however, there appears to be a wide difference in the process of growth as well as form, and when it is remembered that magnificent, almost perfect, palates of Agassizodus have been found in the Carboniferous Measures of Illinois, described by Messrs. St. John and Worthen ("Geol. Survey of Illinois," Vol. VI., p. 311), and comprising a variety of teeth closely resembling those of Orodus, which are arranged almost exactly as are those of the existing Cestracion, little doubt can be entertained that there is in the Cochliodonts a group of fishes whose representatives have long ceased to exist, and which must stand apart and alone in ichthyic development.

Besides the Psammodontidæ, represented by the well-known Psammodus, the Copodontidæ comprise a large assemblage of more or less flat pavement-like teeth from the Armagh limestone. This large assemblage, the result of many years most painstaking collection, is quite unique. In no other locality does it appear that teeth of similar import have been discovered. They have remained in the collection of Lord Enniskillen, undescribed to the present time. Professor Agassiz, during a visit to Florence Court nearly twenty-five years ago, carefully examined the collection and distributed the specimens amongst a number of new genera and species, to which he appended names in manuscript. These have been retained in the following pages in every possible instance.

Some light is thrown on the dentition of Psammodus by specimens in the Bristol Museum, and it appears probable that the idea given by M. de Koninck ("Faune du Calc. Carbon. de la Belgique," p. 42) of the dentition of Psammodus may prove the correct one.

A. Selachoïdei.

Family—Hybodontidæ, Agass.

"Two dorsal fins, each with a serrated spine. Teeth rounded, longitudinally striated, with one larger and from two to four smaller lateral cusps. Skin covered with shagreen."—(*Günther.*)

Genus—Ctenacanthus, Agass.

Ctenacanthus—Agassiz, L., 1833. "Recher. Poiss. Foss.," Vol. III., p. 10.
,, M'Coy, F., 1855. "Brit. Palæoz. Foss.," p. 624.

"Fin-spines, of moderate or large size, compressed, gradually tapering, moderately arched backwards; anterior face narrow, rounded; posterior face concave, with a moderate cavity, the lateral edges bordered by two rows of curved denticles inclined downwards. Surface marked with strong, longitudinal ridges and furrows, pectinated by transverse scales or tubercles. The concealed base of moderate size, rapidly tapering, finely striated."—(*M'Coy.*)

The genus Ctenacanthus is confined to the strata below the Coal Measures, just as the genus Hybodus has only been found in the rocks above. The two genera are very similar in form, and the fishes which were possessed of the spines were evidently closely related in structure and habits. Prof. Agassiz ("Poiss. Foss.," Vol. III., p. 171) considered that the spines of Ctenacanthus and the teeth of Psammodus might have belonged to the same fish, but the discovery of the teeth of Hybodus in close relationship to the position of the spines, has proved beyond doubt that the teeth of that genus bear a close relationship to the pointed cutting teeth of the sharks of the existing species, having a central prominent pointed cone with smaller lateral ones rising from a broad expanded base. The occurrence in considerable abundance of the teeth of Cladodus in the Carboniferous rocks, similar in form to those of the known Hybodus, renders the probability great, that Ctenacanthus was provided with teeth possessing similar characters to those of Hybodus and that the spine of Ctenacanthus and the teeth of Cladodus may have been from the same fish, though no positive proof exists of the relationship.

The Agassizian conception of the genus Ctenacanthus has been enlarged by various authors so as to include a number of specimens, like *Ctenacanthus* (?) *distans*, M'Coy, which it is very probable pertained to quite a different type of fish. The inclusion of such species has been also made by some American palæontologists, as for instance, *C. gracillimus* ("Geological Survey of Illinois," Vol. II., p. 126, pl. xiii., fig. 3), *C. burlingtonensis* and *C. keokuk*, St. J. and W. ("Illinois," Vol. VI., pp. 426, 427, pl. xv., figs. 7, 8), and others. These specimens differ in no respect from some which have been described as Leptacanthus, Ag. (compare *C. gracillimus* with *L. occidentalis*, *op. cit.* pl. xii., fig. 2) and Acondylacanthus, St. J. and W., whilst they present great divergence from the Ctenacanthoid type. A chief characteristic of the latter is the large open posterior groove or pulp cavity extending the whole length of the osseous base and in a few instances still further up the spine. This feature appears to be entirely absent in the long graceful spines indicated above. In the large series from the Armagh limestone there is no evidence of such a cavity opening posteriorly, the internal cavity is terminal and is open only at the end of the base of the spine. After searching through the descriptions of American palæontologists a similar result is obtained. In nearly all cases the basal end is fractured or wanting. This difference may possibly be of even greater than generic importance, and may indicate affinities rather with the Batoidei than the Selachoidei. In the following descriptions it is proposed to remove the variety of spines indicated from the genus Ctenacanthus, and, for reasons hereafter adduced, to place them with the so-called Carboniferous Leptacanths in the genus Acondylacanthus of Messrs. St. John and Worthen; retaining only such species in the genus Ctenacanthus as will fall in with the description of them indicated by Professor Agassiz.

Ctenacanthus major, Agass.

(Pl. XLII., figs. 1, 2.)

Ctenacanthus major—	L. Agassiz,	1837.	"Rech. Poiss. Foss.," Vol. III., p. 10, pl. iv.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 308.
" "	H. G. Brown,	1848.	"Nomencl. Palæont.," p. 355.
" "	"	1849.	"Enumerator Palæont.," p. 649.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 290.
" "	J. Morris,	1854.	"Catal. Brit. Foss.," p. 323.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
" "	Young and Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supplet. p. 70.
" "	Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 61.
" "	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 351.

This spine is described by M. Agassiz as being elegantly arched in the form of a scythe. It attains a length of nearly two feet and is about three inches in diameter at the base. From the base it contracts insensibly towards the superior extremity, ending in a fine point. The surface is ornamented by a large number of small longitudinal ridges with intermediate rounded grooves. The ridges are divided by closely-imbricating obliquely transverse folds, which project over the groove on each side and form a denticulated margin. On the posterior surface of the spine, but only near the point, there extends a double row of small denticles. The latter are rounded, recurved towards the base, and pointed. The sides of the spine are compressed, but slightly rounded midway betwixt back and front. The transverse section is oval (Pl. XLII., fig. 1*a*), rounded posteriorly, and somewhat sharply accuminate anteriorly. The line of demarcation between the exposed part of the spine and the smooth base which was embedded in the flesh, is very oblique. A deep and open cavity extends along the posterior face. It is prolonged in the form of an enclosed oval cavity almost to the apical extremity of the spine.

If the size of the fish, to which these spines belonged, is proportionate to the size of living species which are possessed of dorsal spines, it must be admitted that it attained to gigantic proportions, and is, perhaps, the largest example of Ichthyodorulite occurring in the Palæozoic rocks of this country. It is extremely probable that Ctenacanthus had two spines, one each before the anterior and posterior dorsal fins. It is known that such was the case in Hybodus, as well as several other Selachoids which occur in a fossil state, and as found in the dog-fish existing on our own coasts at the present day. The spine represented on Pl. XLII., fig. 2, was probably in front of the second one, (Pl. XLII., figure 1), which is slightly shorter, and broader and has a more robust character.

The spines of this genus bear a marked resemblance to *Ctenacanthus maximus*, described L. G. de Koninck (" Faune du Calcaire Carbonifère de la Belgique," Pt. I.

p. 68, pl. vii., fig. 1), both on account of their size, their general form and the character of their external decoration. The description of the spines given by Dr. de Koninck is almost identical with that of Professor Agassiz, in the "Poissons Fossiles," of the Bristol species, except that the transverse section is more decidedly oval and is not so sharply produced anteriorly. This character, however, is not of sufficient importance to form a specific difference, but, not having had an opportunity to examine the Belgian species, I do not feel justified in placing it definitely with *Ctenacanthus major*, Ag.

Formation and locality: Mountain Limestone, Bristol.
Ex coll. 1. Earl of Enniskillen; 2. Bristol Museum.

Ctenacanthus tenuistriatus, Agass.

(Pl. XLIII., figs. 1, 2.)

Ctenacanthus tenuistriatus—	L. Agassiz,	1837.	"Poiss. Foss.," Vol. III., p. 11, pl. iii., figs. 7–11.
" "	P. de M. Grey Egerton,	1839.	"Catalogue of Fossil. Fish."
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Bd. I., Abth., III., p. 308.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 355.
" "	J. Morris,	1854.	"Cat. British Foss.," p. 323.
" "	F. J. Pictet,	1854.	"Traité de Palæont.," Vol. II., p. 290.
" "	Morris and Roberts,	1862.	"Quar. Jour., Geol. Soc.," Vol. XVIII., p. 100.
" "	P. de M. Grey Egerton,	1869.	"Catal. Type Specimens of Fossil Fishes," p. 5.
" "	Young & Armstrong,	1871.	"Transactions Geological Society, Glasgow," Vol. III., Supplement, p. 70.
" "	Armstrong, Young, and Robertson,	1876.	"Catalogue of the West. Scot. Fossils," p. 61.
" "	J. J. Bigsby,	1878.	"Thesaur. Devon.-Carb.," p. 351.
" "	L. G. de Koninck,	1878.	"Annales de Musée Royal d'histoire naturelle de Belgique," Vol. II., p. 67, pl. vii., fig. 2.

Spine, of moderate size, a perfect specimen being fourteen to fifteen inches in length, greatest breadth two inches. The specimens described by Prof. Agassiz were very imperfect, and afforded insufficient material for a complete description. The lower portion of the spine is almost straight, with a very slight curvature backwards; base rounded; the upper part, about one-fourth the length of the whole, contracts rapidly in diameter, posterior surface deeply curved, and terminating with an acutely pointed apex. It is this portion of the spine which is represented in the "Poissons Fossiles," Vol III., pl. iii., fig. 7. The lateral surfaces are compressed and covered with minute longitudinal striæ, with intervening grooves, about the same width as the ridges. The ridges increase in number towards the base, by bifurcation. Each ridge is characterized by minute transverse foldings of the surface. This species differs considerably from *C. major*, Ag., in the paucity of the ridges, not only are the longitudinal ridges more slender than those of *C. major*, but those towards the posterior portion of the surface are considerably finer and smaller than those on the anterior surface. The anterior border is well rounded,

the surface striæ are large and broad, and in some instances, almost smooth. The base is divided from the exposed portion of the spine by an oblique line, and occupies about one-fourth of the entire length of the spine. An open cavity extends from the base towards the superior extremity of the spine. It is not so deep as in the majority of the species of Ctenacanthus, but it remains open to a higher point than in any other species, and only the uppermost fourth of the spine is enclosed. A transverse section exposes a small cavity in proportion to the thickness of the spine ; towards the base the anterior wall of the spine is very thick ; higher in the spine, the internal canal presents the form of a much compressed oval, but still nearer the apex the section is less compressed.

The specimen described by M. de Koninck from the neighbourhood of Felay, in Belgium, appears to differ from the Bristol specimens in the longitudinal striæ being broader and less numerous, and in the possession of posterior denticles of which there is no evidence in the Bristol type.

Formation and locality : Mountain Limestone, Bristol.

Ex coll. Earl of Enniskillen.

Ctenacanthus heterogyrus, Agass., MS.

(Pl. XLIV., figs. 1, 2, 3.)

Ctenacanthus	heterogyrus	—L. Agassiz,	1837.	"Rech. Poiss. Foss.," Vol. III., p. 177 (ind).
,,	,,	Portlock, J. E.,	1848.	"Rep. Geol. Survey, Fermanagh, &c.," p. 461.
,,	,,	Giebel, C. G.,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 309.
,,	,,	Bronn, H. G.,	1848.	"Nomencl. Palæont.," p. 355.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 649.
,,	,,	Morris, J.,	1854.	"Cat. Brit. Foss.," p. 325.
,,	,,	Pictet, F. J.,	1854.	"Traité de Paléont.," Vol. II., p. 290.
,,	,,	M'Coy, F.,	1855.	"Brit. Palæoz. Foss.," p. 625, pl. 31, fig. 32.
,,	,,	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	Bigsby, J. J.,	1878.	"Thesaurus Devon.-Carb.," p. 351.
,,	,,	De Koninck, L. G.,	1878.	"Faune Calc. Carb. de la Belgique," p. 66, pl. vii., fig. 3.

This species, named by Prof. Agassiz, but not described, was described by Prof. M'Coy in the following terms:—"Very short, rapidly tapering ; length of exposed portion three inches, at which length it forms an obtuse point, from a width at base of ·5 inch (measured at right angles to the length), very slightly arched, the posterior outline nearly straight, the anterior one convex. Sides flattened, converging to the narrow anterior face, which is occupied by a flattened smooth ridge about twice as wide as those of the sides ; lateral ridges extremely irregular in size, shape and marking ; rather thick, separated by deep sulci less than half their width ; ridges averaging four in two lines, at four lines in diameter, some of them thinning out above at irregular distances, other pairs uniting branchwise into one above, some appearing to taper to both ends ; most of the ridges are nearly smooth in a great part of their course, or showing a more or less distinct crenulation on their sides (about three in the space of one line), from small opposite

lateral tubercles; in certain irregular spots these lateral tubercles increase in size and strength, and distinctly cross the ridges by becoming connected across them; in several of the ridges, particularly towards the base, the transverse tuberculation and notching becomes so distinct, that the ridge is separated into a row of triangular tubercles about half a line long.

"The extreme irregularity of the ridges of this species, no two of them being quite alike, and several of them totally changing their aspect after short distances, easily distinguish this species from its congeners. The finely striated base is of rather small size, and rapidly tapering, the line of separation between it and the ridged exterior being very oblique."

The specimens which served Prof. M'Coy as types for this species, appear from the figures which he has given to have consisted of a few detached fragments of the spines. Since that description was written, many specimens have been obtained from the limestone at Armagh, and I am enabled to give drawings of perfect specimens, by the kindness of Lord Enniskillen. The specimen (Pl. XLIV., fig. 1) is five inches in length, its greatest breadth being ·8 of an inch, from which point it tapers in either direction, gradually, towards the superior extremity, ending in an acute point, and more rapidly towards the base, which is obtusely rounded. The exposed portion of the surface, extends three inches from the point along the anterior margin and is divided from the base by an oblique line, extending to the posterior margin, which it reaches at a distance of 2·2 inches from the apex. The base is smooth, or finely striated and occupies an area almost equal to that of the exposed part. Along the posterior margin, on each side, there is a row of obtusely rounded denticles.

A peculiarity not observed by M'Coy in the arrangement of the longitudinal ridges is, that they extend parallel with the posterior margin, which is almost straight, whilst those nearer the front of the spine run out along the anterior margin.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Ctenacanthus brevis, Agass.

(Pl. XLIII., fig. 3.)

Ichthyodorulithes brevis, Buckl. and De la Bèche (MS.)				
Ctenacanthus brevis—	L. Agassiz,	1837.	"Rech. Poiss. Foss.," Vol. III., p. 11, pl. ii., fig. 2.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. II., p. 309.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 355.
" "	"	1849.	"Enumerator Palæont.," p. 649.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 290.
" "	J. Morris,	1854.	"Catal. Brit. Foss.," p. 323.
" "	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
" "	Young and Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt. p. 70.
" "	Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 61.
" "	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 351.

Prof. Agassiz in his description of this spine says, "I know as yet only one figure of this spine, which has been communicated to me by Dr. Buckland, and which I have had copied in the plate cited above. There is represented the inferior part of a large spine, very thick in proportion to its length, of which the exposed surface is covered with small transversely striated tubercles, disposed in longitudinal and parallel series. The base is smooth; the line of demarcation between the part embedded and that which was exposed is very oblique, and arched towards the anterior margin. The posterior basal cavity is very large and deep."

A perfect specimen in the cabinet of the Earl of Enniskillen is nine inches in length; the greatest breadth is 1·4 inches, at the junction of the exposed and basal portions. The posterior face is almost straight, except for a short length near the superior extremity, which is deeply curved. The anterior margin is gracefully arched from the apex to the base. The proportion of the spine which was embedded in the body of the fish is extremely large, and forms about two-thirds of the whole surface. The smooth base extends 4·5 inches along the anterior surface, from which it extends, with a very oblique curvature, to 1·5 inches from the point on the posterior surface. There is no appearance of posterior denticles.

This species in some respects bears a close resemblance to *Ctenacanthus spectabilis*, St. John and Worthen, ("Geological Survey of Illinois," Vol. VI., p. 420, pl. vi., fig. 1). In the latter, however, the base is much smaller in proportion to the exposed part of the spine, and the angle dividing the two is not nearly so oblique as in *C. brevis*, Ag. The peculiar way in which the costæ are deflected towards the posterior margin in the Kinderhook specimen, does not occur in the Armagh one, and the form of the tubercles set along the costæ of the two species is quite distinct.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Ctenacanthus denticulatus, M'Coy.

(Pl. XLIV., fig. 4.)

Ctenacanthus denticulatus	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd Ser., Vol. II., p. 116.
,, ,,	J. F. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 290.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 323.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 625, pl. 3 K, fig. 16.
,, ,,	J. J. Bigsby,	1878.	"Thesaur. Devon.-Carb.," p. 351.

"Spine, nearly straight, slightly curved towards the apex; length of naked portion 5·5 inches, length of the rapidly tapering base two inches, width near base, nine lines; section truncato-elliptical, sides slightly convex, front narrow, rounded; posterior face wide, depressed, concave at both sides, with an obtuse ridge in the middle, the lateral angles closely set with a row of numerous, small, conical, downward-curved teeth on each, their own length apart; longitudinal ridges

rounded, less than their own diameter apart (about four in two lines in the middle of the ray); they are a little wider at base than towards the apex, increasing in number downward by dichotomy; the sides of each ridge are denticulated, with sharp recurved teeth extending half way across the intervening spaces, the denticle of one side connected with its fellow on the other by a slightly oblique fold across the ridge, each pair being separated from that above and below by about the thickness of the ridge; near the posterior margin on each side are four or five ridges much smaller than the rest, crossed by oblique blunt tubercles."—*M'Coy.*

The ornamentation of the longitudinal ridges of this species bears a great resemblance to that of *Ctenacanthus gradocostus*, St. J. and W. ("Geol. Survey of Illinois," Vol. VI., p. 425, pl. xv., figs. 2, 3); a reference to the enlarged drawing of the costæ, *loc. cit.* pl. xv., fig. 3b, and comparison with Pl. XLIV., fig. 4a, representing the present species, will render this more clear than description. The ridges of the Quincy specimen are triangular in section, whilst those of *C. denticulatus* are rounded. The general form and character of the two species are similar as far as can be gathered from the imperfect specimens figured and described by Messrs. St. John and Worthen.

Formation and locality: Dark shale above the Yellow Sandstone of Monaduff, Drumlist, N. Ireland.
Ex coll. Woodwardian Museum, Cambridge.

Ctenacanthus limaformis, Davis.

(Pl. XLIV., fig. 5.)

Spine, medium size, robust and strong, diameter large in proportion to its length. Specimen imperfect, a small part of the superior extremity is missing as well as a larger part of the base. The anterior margin of the spine is arched slightly, and along the whole of the exposed portion is a board band of ganoine divided into small file-like segments, which appears to be the peculiar characteristic of this species. The length of the part preserved is 4·50 inches.

Locality and formation: Mountain Limestone, Bristol.
Ex coll. Earl of Enniskillen.

Ctenacanthus salopiensis, Davis.

(Pl. XLIV., fig. 6.)

Fin spine, when perfect about ten inches in length, and at its broadest part 1·5 inches in diameter. The base or part buried in the integument is large in proportion to the remainder, being nearly one-third the length of the spine. Its anterior margin curves rapidly towards the end and is 2·5 inches in length, the posterior is 4·5 inches and considerably straighter. The line dividing the base from the upper portion of the spine is very oblique. The exposed part is slightly curved towards the apex principally along its anterior margin. In transverse section the spine is triangularly elliptical, widest from back to front, much compressed at the sides; the posterior diameter is greater than the anterior, the latter almost pointed. The

anterior surfaces are much compressed and ornamented by numerous longitudinal ridges; very small and separated by furrows their own diameter in width. Both the ridges and furrows are largest near the base, towards the apex of the spine they decrease considerably in size especially along the posterior margin, into which they are ultimately absorbed and disappear. The furrows are deep in proportion to their width; there are about forty on each side. Transversely across the ridges there extend minute plica or folds, these are continued down each side of the ridge and join, at the base of the furrow, a similar fold from the side of the opposite ridge. Each separate ridge has the appearance of a long string of minute cups the narrow base of each being placed in the extended mouth of the one preceding it, and when highly magnified presenting an extremely beautiful appearance. The anterior face of the spine is slightly rounded but accuminate and is not characterized by any peculiarity in the ridges which continue to cover it. A wide and deep open cavity occupies the lower posterior portion of the spine; about equidistant between the base and apex this becomes enclosed and extends far towards the latter. The enclosed cavity is very large and the sides of the spine forming its walls are proportionately thin. The teeth extending along the postero-lateral angles are not preserved with sufficient distinctness to be described, though the broken stumps are distinguishable, the teeth having been broken away with the matrix.

The ornamentation of the ridges of this species bears a slight resemblance to that of *C. crenatus*, Ag., or *C. denticulatus*, M'Coy. In the former the crenulations are formed by a row of small transverse tubercles extending obliquely down the sides of the ridges and rarely passing over its summit, whilst in *C. denticulatus* the sides of the ridge are denticulated with sharp recurved teeth extending half way across the intervening hollow, and slightly connected across the ridge. The characters of both are sufficiently distinct from the species now described, even if the general form of the spine was less distinct in each case, whilst near the same length as *C. denticulatus*, it is double its breadth, and there are considerably more than double the number of ridges on each lateral surface. *Ctenacanthus speciosus*, St. John and Worthen ("Geological Survey of Illinois," Vol. VI., p. 424, pl. xiv., figs. 3, 4), appears to be closely related to this species. It may be distinguished by the lateral striation being closer, with narrower interspaces, and the transverse ornamentation of the ridges not extending so far across the intermediate furrow.

Locality: The specimen described is from Oreton in Salop. Specimens have also been found at Bristol which possess the same characters and are without doubt the same species; they are, however, of a somewhat stronger and more robust appearance than the Salopian specimens.—All are from the Mountain Limestone.

Ex coll. Earl of Enniskillen.

Ctenacanthus dubius, Davis.

(Pl. XLIV., fig. 7.)

A spine 2·5 inches in length, and ·5 of an inch in greatest breadth. Slightly curved on the posterior margin, considerably more so on the anterior one. The

base occupies nearly one-fourth the length of the spine. The spine is crushed and a part of the base has disappeared; from the widest part, a little higher than the line dividing the base from the exposed part of the spine, it becomes rapidly narrower and ends in a fine point. The sides are divided into six or eight striæ, not so broad as the intervening hollows; the striæ are simple and coated with enamel.

Locality: Armagh, Mountain Limestone.
Ex coll. The Earl of Enniskillen.

Ctenacanthus lævis, Davis.

(Pl. XLV., fig. 1.)

Fin spine, about five inches in length and at its broadest part ·6 of an inch wide. From the oblique basal line it tapers with a gradually diminishing diameter to an obtuse point. The spine is gently but decidedly curved in outline: elliptical in transverse section. The lateral faces are much compressed, and are covered with longitudinal ridges, extending from the basal line parallel to the posterior margin towards the point. The ridges are most numerous near the base where the spine is broadest, and become fewer by running into, and being absorbed by, a median ridge stronger than the others and forming a keel along the anterior margin the whole length of the exposed part of the spine. The ridges, twenty-four in number at the base, are wider than the intermediate furrows, and present a broad flattened surface of shining enamel. The relative size of the costæ and intercostal spaces is maintained through the whole length of the spine, being equally wide near the apex as at the base. The base of the spine is comparatively small, of the usual fibrous structure; the line dividing it from the exposed portion is straight and forms a very obtuse angle to the longitudinal axis of the spine. A deep channel extends along the basal portion, which becomes enclosed and forms an internal cavity extending nearly to the apex of the spine. The cavity is oval in section and is situated nearer the posterior than the anterior surface, equidistant from the sides. Along the posterior surface there extends a deep circular groove, the postero-lateral angles of which are armed for some distance below the apex with recurved, rounded, sharply-pointed denticles separated by spaces about double their own diameter. Lower down, the angles are devoid of denticles, somewhat more rounded, and quite smooth.

This form of spine is comparatively rare, the specimen of which a figure is given is imperfect, the apex being broken off and a portion of the base fractured. Other examples are slightly more curved than the spine described, but are otherwise in all respects characterized by the same peculiarities. The difference in convexity may be a little irregularity, and due to there having been a spine in front of each of the two dorsal fins, one having been before the anterior and the other the posterior dorsal fin.

A transverse section of this species gives a triangle whose sides are connected by a base much shorter, and in this respect it is distinguished from *Ctenacanthus plicatus*, next described, in which the section forms an almost equilateral triangle.

Locality : Mountain Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Ctenacanthus plicatus, Agass.

(Pl. XLV., fig. 4.)

Onchus plicatus—	L. Agassiz,	1833.	"Rech. sur les Poiss. Foss.," Vol. III., p. 177 (ind).
" "	J. E. Portlock,	1843.	"Rept. on Geol. Fermanagh, &c.," p. 461.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 302.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 843.
" "	"	1849.	"Enumerator Palæont.," p. 652.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 284.
" "	J. Morris,	1854.	"Catal. Brit. Foss.," p. 334.
" "	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101.
" "	J. J. Bigsby,	1878.	"Thesaur. Devon.-Carb.," p. 359.

Spine, medium size, slightly curved, rather rapidly tapering towards the point, imperfect; length preserved three inches, probable length when perfect about 4·5 to 5 inches, greatest diameter at line of insertion ·65 of an inch ; base, osseous, striated, one-fourth the entire length of the spine : line dividing base and exposed surface, oblique, with convexity towards the base. Transverse section, triangular, sides acuminate above, base curved inwards, two-thirds the length of one side. Lateral surface covered by a number of broad plicated ridges, at 1·7 inches from the base, nine or ten in number, increasing by dichotomy to more than double that number towards the base, and apparently decreasing upwards. A peculiarity in the ridges of this species consists in their first dichotomizing, and then the two branches lower down coalescing with the ridges on either side of them, to become again separated a quarter of an inch nearer the base. A representation of this peculiarity is given on Plate XLV., fig. 4a. The sides are very flat, meeting anteriorly at a sharp angle without median keel, the anterior margin being formed by the repeated inosculation of the lateral ridges. The latter present a steep, almost perpendicular face towards the anterior margin, whilst in the opposite direction they slope gradually downwards, presenting something like the appearance of overlapping tiles; a series of minute striations traverse the ridges in an oblique line parallel with that of the base. Posterior surface hidden by the matrix.

This spine was named by Prof. Agassiz, *Onchus plicatus*, and is the type specimen from the late Admiral Jones' collection. The specimen which is described above as *Ctenacanthus lævis*, was also named in MS. as belonging to the same species, in the collection of the Earl of Enniskillen. The principal characteristic given by Prof. Agassiz to distinguish Ctenacanthus from Onchus is that it is possessed of posterior denticles, the latero-posterior angles of Onchus being smooth and free from

teeth. In the specimen from the Enniskillen collection the posterior margin is exposed and a row of recurved teeth is very clearly exhibited. Unfortunately the specimen forming the type of Agassiz is buried in a hard matrix and the posterior margin cannot be seen, but the two are so clearly related and possess so many features in common than it is very probable, could the surface be exposed without too great risk to the specimen that it would be found to possess posterior denticles. After careful consideration it appears advisable to consider the specimen as belonging to the genus Ctenacanthus.

The more rapidly contracting form of this species, the absence of an anterior median keel, and the peculiarities of the ridges, separate it specifically from *Ctenacanthus lævis.*

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Geological Society's Museum.

Ctenacanthus sulcatus, Agass.

(Pl. XLV., fig. 3.)

Ichthyodorulithes bristoliensis, Buck. and De la Bèche (MS.)

Onchus sulcatus—L. Agassiz,		1833.	"Rech. Poiss. Foss.," Vol. III., p. 8, pl. 1, fig. 6.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 302.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 843.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 652.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 284.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 334.
,, ,,	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 359.

Spine, more or less arched, medium size, perfect example five to six inches in length, breadth 1·0 inch, gradually tapering towards the point, base one-fourth the length of the spine, division between base and exposed part forms a slightly sigmoidal curvature: transverse section oval, much compressed laterally; internal cavity situated near posterior surface, comparatively small and broad. The lateral surfaces are ornamented by peculiar longitudinal ridges, which are described by Prof. Agassiz as being especially distinguished by the irregularity of their furrows and of the ribs which separate them, some of them being double the width of others; they, however, have all a very flat surface. The anterior surface is formed by a broad ridge which is divided near the base into three branches, it is rounded and more thickly coated with enamel than the lateral ridges. The posterior cavity is large, and open at the basal extremity, a deep groove being continued on the external surface towards the apex of the spine. It appears doubtful whether specimens of this species have been found which exhibit the latero-posterior angles with sufficient clearness to show the posterior denticles. Prof. Agassiz states that Dr. Buckland sent to him a drawing of a specimen, well preserved, from which it appeared that the spine had a double row of small denticles along the superior

portion of the posterio margins. Dr. Buckland also stated in a manuscript description of the spine that there appeared on its posterior surface, two rows of regular tubercles. Prof. Agassiz considers that the denticles may be merely due to the termination of the longitudinal furrows. After some hesitation, however, he placed the spine in the genus Onchus, at the same time recognizing its resemblance to Hybodus.

After careful study of specimens, there appears sufficient evidence of posterior denticles; and the close resemblance, and evident relationship to the species forming the genus Ctenacanthus, renders necessary its removal to that genus.

This species bears some resemblance to *C. lævis* and *C. plicatus*, from the latter it will be distinguished by its greater breadth and its greatly compressed oval section, and from the former by the longitudinal ridges on each side, which in *C. lævis* run parallel with the posterior margin and in *C. sulcatus* with the anterior one.

Formation and locality: Carboniferous Limestone, Bristol.
Ex coll. Bristol Museum.

Ctenacanthus pustulatus, Davis.

(Pl. XLV., fig. 2.)

Length of spine nearly four inches, greatest width at the base of the exposed part ·5 of an inch. The spine is slightly curved, the anterior border more so than the posterior. The base extends 1·4 inches along the posterior border, and 1·2 of the anterior one is occupied by it. The remaining portion of the spine contracts gradually to a point and is covered with longitudinally arranged striæ, most numerous at the base of the exposed portion and diminishing in number towards the apex, not by anastomosing but by the gradual thinning out and disappearance of the ridges The surface of the striæ or ridges is coated with ganoine and is quite smooth; along the posterior part of the spine they are about the same diameter as the intermediate hollows, but near the anterior portion the hollows occupy a greater space than the ridges. The hollows are covered by numerous pittings arranged in longitudinal rows parallel to their own direction, and there are also in the most anterior ones several detached ganoine-tipped pustules rising to a level with the ridges. The lateral surface is slightly compressed, rather more so towards the posterior border. Along the whole length of the posterior margin there is a double row of hooks or small denticles, broad at the base, culminating in an obtuse point.

Locality: Mountain Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Ctenacanthus crenulatus, Agass., MS.

(Pl. XLV., fig. 6.)

Ctenacanthus crenulatus—L. Agassiz,	1833.	"Rech. Poiss. Foss.," Vol. III., p. 177.
,, ,, J. E. Portlock,	1843.	"Geol. Report, Londonderry, &c.," p. 461.
,, ,, C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3. p. 309.
,, ,, H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 355.
,, ,, ,,	1849.	"Enumerator Palæont.," p. 649.
,, ,, J. Morris,	1854.	"Catalogue Brit. Foss.," p. 323.
,, ,, F. J. Pictet.	1854.	"Traité de Paléont.," Vol. II., p. 290.
,, crenatus— F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 624, 3, I., fig. 31.
,, crenulatus—Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.

This specimen, which was then a part of the collection of Admiral Jones, M.P., served as the type of this species, was named but not described by Prof. Agassiz. The following is the description in the "Palæozoic Fossils" :—Fin-spine, gradually tapering, moderately compressed, sides rather flattened, converging to a narrow, rounded, anterior face : each side with about ten or eleven, nearly equal, regular, rounded ridges, parted by sulci, about their own width apart, (at six lines wide there are five ridges in two lines) each ridge with a row of small transverse tubercles, strongly crenating the sides, down which they extend obliquely; those of each side usually opposite, but sometimes alternate, generally leaving the middle of each ridge smooth, but occasionally in some spots the small tubercles from each side of a ridge meet on the middle, forming transversely rhomboidal tubercles, attenuated at the lateral extremities : five lateral tubercles in the space of one line. The posterior cavity is rather large.

"The length of this species is unknown, but it is probably at least four inches. The species is easily recognised by the regular ridges being crenulated, or milled, like the edge of a coin, by the small elongate tubercles, projecting at right angles from the sides of the ridge, and usually not encroaching on its centre."—(*M'Coy.*)

During a recent visit to Cambridge, I was unable to find the specimen which was the type of this genus. It may and in all probability was, described from the private collection of Admiral Jones, and afterwards consigned to some other collection; perhaps lost.

Locality and formation : Mountain Limestone, Armagh.

Ex coll. Woodwardian Museum, Cambridge

Ctenacanthus rectus, Agass. MS.

(Pl. XLV., fig. 5.)

Onchus rectus—L. Agassiz,	1833.	"Rech. sur les Poiss. Foss.," Vol. III., p. 177.
,, ,, J. E. Portlock,	1843.	"Geol. Report, Londonderry, &c.," p. 461.
,, ,, C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 302.
,, ,, H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 843.
,, ,, ,,	1849.	"Enumerator Palæont.," p. 652.
,, ,, J. Morris,	1854.	"Catal. Brit. Foss.," p. 334.
,, ,, F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 284.
,, ,, Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101

The type of this species is in the museum of the Geological Society, London, in the collection presented by Admiral Jones. It is an imperfect spine, 1·25 inches in length, ·2 inch broad, and tapering to a point. The basal portion is wanting, and the specimen appears to be the superior extremity of a specimen perhaps three or four inches long when perfect. Its sides are ornamented by smooth, longitudinal ridges; a larger one forming a carina along the anterior margin. Between the ridges are spaces wider than the ridges, in the flat bases of which are a number of minute striæ running parallel with the ridges. The spine is enveloped in the matrix, and the form of a section is not perceptible.

This little specimen appears to be unique. It was apparently considered by Prof. Agassiz to be an Onchus, and was named by that learned ichthyologist *O. rectus.* There is, however, no visible characteristic which will distinguish it from Ctenacanthus; and as in all probability posterior denticles exist, but are hidden by the matrix, it is thought better to include the specimen in this genus.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Geological Society's Museum, London.

Genus—Acondylacanthus, St. John and Worthen.

Leptacanthus—L. Agassiz,	1833.	"Poiss. Foss.," p. 176. MS., (partim.)
,, F. M'Coy,	1855.	"Brit. Palæoz. Fossils," p. 633.
Ctenacanthus (partim)—F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 625.
Leptacanthus—Newberry and Worthen,	1866.	"Palæont. Illinois," Vol. II., p. 116.
Acondylacanthus—St. John and Worthen,	1875.	"Palæont. Illinois," Vol. VI., p. 432.

"Fin-rays, long, gradually tapering, laterally compressed, and moderately curved posteriorly. Lateral faces longitudinally fluted, the costæ being smooth (or crenulated) and enamelled, increasing by occasional bifurcation, perhaps more rarely by implantation. Posterior face uniformly excavated longitudinally, apparently without median keel; postero-lateral angles bearing a row of downward-hooked denticles, which extend in the majority of species well towards the base. Pulp cavity occupying the posterior half or more of the spine. Base unknown."—(*St. J. and W.*)

Prof. Agassiz, in his work "Poissons Fossiles," Vol. III., p. 27, has instituted the genus Leptacanthus, comprising several species of Ichthyodorulites from the Jurassic formation, including the Lias. They are long and slender spines; sides longitudinally striated, latero-posterior margins armed with teeth, and the anterior edge sharp and keeled; base not known, but probably like Hybodus.

In the same work, page 176, Prof. Agassiz gives the name *Leptacanthus priscus* to a spine from the Carboniferous Limestone of Armagh, without observation.

In the "British Palæozoic Fossils," p. 633, Prof. M'Coy places two species, viz.:—*L. junceus* and *L. jenkinsoni* in the genus Leptacanthus, observing that the genus is a Carboniferous and Oolitic one.

Messrs. Newberry and Worthen, in 1866, described a spine which was doubtfully

referred to the genus Leptacanthus, viz., *L. occidentalis*, with the remark that there seems "little probability that they are generically identical with those from the Oolite." The general form is similar, but the striated or obscure and confusedly costate surface of the typical Leptacanthi must have given them an aspect widely different from that of these spines so uniformly and regularly ribbed throughout. He further points out, that in no instance have teeth been found in the Jurassic and Carboniferous rocks, which are common to both and might have belonged to the fish bearing the spines Leptacanthus. The close resemblance of these spines with the slender and compressed forms which have been included in Ctenacanthus, such as *C. distans*, M'Coy, and *C. gracillimus*, N. and W., is also remarked, and a suggestion made that these slender and flattened species of Ctenacanthus and the Carboniferous Leptacanthus should be combined to form a new genus separate alike from Ctenacanthus and Leptacanthus.

This suggestion was to some extent carried out by Messrs. Orestes St. John and A. H. Worthen, in the sixth volume of the "Geol. Survey of Illinois," p. 432, by the formation of the genus Acondylacanthus, with two species from the Kinderhook fish-bed and the Keokuk limestone respectively, viz.:—*A. gracilis* and *A. æquicostatus*. This genus is also considered to embrace the following described species, all of which pertain to the Carboniferous period: *Leptacanthus junceus*, M'Coy, *L. jenkinsoni*, M'Coy, *L. occidentalis*, N. and W., and *Cladodus tenuistriatus*, Romanowsky. The last named, though evidently a spine of Leptacanthus, was considered by Col. Romanowsky to be associated specifically with the teeth of Cladodus, from the fact that the two were found associated with each other.

The rearrangement as suggested by St. John and Worthen appears in every sense preferable and will be followed in the present instance.

Acondylacanthus colei, Davis.

(Pl. XLV., fig. 7 ; Pl. XLVI., fig. 1.)

Fin-spine, gently arched and gradually tapering to a fine point. Base imperfect; length preserved 5·5 inches, greatest diameter at base ·35 inch, which steadily diminishes towards the apex. Transverse section rounded anteriorly and laterally, posterior flattened or depressed; internal cavity, large and round. Sides ornamented with a number, about twelve, of delicate, enamelled costæ, extending longitudinally, parallel with the anterior surface, towards the base they increase by bifurcation; the intermediate hollows are smooth and narrow. The anterior margin is rounded, the longitudinal striæ of the sides are continued anteriorly; there is no median keel. Posterior face, broad, somewhat deeply channeled. Latero-posterior angles sharply defined, bearing on each side a row of obtusely pointed, widely separated denticles.

The spines comprised in this species have been classed with those of *Acondyla-*

canthus distans, in the cabinets of Lord Enniskillen, but a comparison with the figure of that spine given on Plate XLVI., fig. 5, will prove sufficiently conclusively, that the two forms are quite distinct. *A. colei* bears a nearer resemblance to *A. equicostatus*, St. John and Worthen ("Geol. Illinois," Vol. VI., p. 634, pl. xvi., figs. 12, 13), but it differs from that species in its more robust aspect, in the roundness of its section, and, so far as can be ascertained—for the posterior portion of the spine is slightly crushed—in the greater width of the posterior groove.

I have taken the liberty to dedicate this species, which I regard as the type of the genus amongst British species, to the Earl of Enniskillen, whose magnificent collection forms the basis on which this memoir is built.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Acondylacanthus tuberculatus, Davis.

(Pl. XLVI., fig. 4.)

Spine, imperfect; the point and base not present. Remaining portion 2·5 inches in length, diameter nearest basal end ·35 inch, gradually tapering to a point. Spine when perfect probably four inches in length. It is slightly curved, more so on the anterior than the posterior surface. Transverse section of spine is triangularly elliptical, widest posteriorly, and somewhat accuminate anteriorly. Lateral surfaces compressed, covered with smooth enameled costæ, about twelve in number near the basal extremity, and decreasing to five or six near the apex. The intermediate hollows are half the diameter of the costæ, deeper than wide. The anterior surface is marked by a median keel, consisting of a similar ridge to those on sides, but larger and slightly broader. The ridge is coated with glistening enamel, produced to form a series of small tuberculose prominences, separated from each other by about their own diameter; near the apex of the spine these tubercles become considerably smaller in size, more closely approximated, and somewhat irregular in disposition. The posterior surface channeled in basal portion, the cavity becoming enclosed, and continuing to within a short distance of the end. Each latero-posterior angle is armed with a row of acutely pointed, round, recurved denticles, springing from a prominent and continuous ridge of ganoine which extends along and forms the angle independently of the lateral costæ. The base not known.

The species most nearly related to this one appear to be *Ctenacanthus* (?) *burlingtonensis* and *C. keokuk*, derived respectively from the limestones indicated by their specific names at Iowa and Illinois, and described by Messrs. St. John and Worthen in the "Palæontology of Illinois" (Vol. VI., pp. 426, 427, pl. xv., figs. 6, 7, 8). The two approximate very closely in specific characters and, according to the authors named, where a considerable series are together, it is not without difficulty

and doubt that they can be separated. The Armagh specimen differs from the American ones in being smaller, and somewhat shorter in proportion to its breadth. Both the species named differ from *A. tuberculatus,* in possessing a much larger number of lateral costæ, and in the latero-posterior denticles being blunt and obtuse, short, and more widely separated. The costæ, also, nearest the anterior margin are tuberculose, whilst those of the Armagh specimen are quite smooth and simple.

Formation and locality: Mountain Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Acondylacanthus distans, M'Coy.

(Pl. XLVI., fig. 5.)

Ctenacanthus distans	—F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd Ser., Vol. II., p. 116.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 323.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 290.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 625, pl. 3 k, fig. 15.
,,	,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.

"Spine, compressed, gently arched, very long, slender, tapering at the rate of only three lines in five inches; posterior face with two rows of numerous, small, short, conical compressed teeth, slightly bent downwards, rather more than the width of their base apart; sides flattened with about ten or twelve close, flattened, longitudinal ridges of irregular width, the broadest occasionally subdividing as they approach the base, all the ridges crenulated by small tubercles, about double the thickness of the ridge from each other; those on the anterior ridges are transverse and slightly oblique, while those nearer the concave margin are smaller, and assume the appearance of lengthened nodulose swellings as in Physonemus.

"This is a remarkably long and slender ray; one specimen in the University collection, of which a considerable portion of the apex must be lost, measures six inches in length, and only six lines in width at the broadest part near the base, the broken distal extremity being three lines wide, which would probable indicate a further inch and a half of length. The portion of the base inserted in the flesh is small and gradually tapering. I am not certain of the exact form of the section,"—(*M'Coy.*)

This species is in every respect, except that the longitudinal ridges are crenulated and not smooth, a good example of the genus Acondylacanthus. In the Enniskillen collection, though there is a large number of specimens, there is not one with the basal portion perfect, and it may be inferred that the Ctenacanthus type of base with a wide, open, posterior sulcus did not exist; if it had—and other examples of that genus may be taken as guides—some of the specimens would have had the base preserved. It rather appears probable that the opening was terminal, and that a very small portion of the spine was embedded in the flesh. The two species named

by St. John and Worthen, *Ctenacanthus burlingtonensis* and *C. keokuk*, should also be removed to this genus.

This species differs from *A. tenuistriatus*, Davis, in having fewer and broader longitudinal ridges, and in the surface of the ridges being more boldly crenulated.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Acondylacanthus tenuistriatus, Davis.

(Pl. XLV., fig. 8.)

Spine, imperfect at both ends, five inches in length, ·45 inch wide at basal end, from which it gradually diminishes to ·3 inch at the opposite one. Transverse section sub-triangular, sides much compressed and slightly rounded, anteriorly forming an acute angle, latero-posterior angles sharp, base slightly concave, internal pulp cavity sublenticular in section, probably terminal at the base, without open basal cavity. The spine is gently and uniformly arched posteriorly. The sides are covered with about twenty smooth, enameled ridges occasionally slightly beaded by excrescences, separated by equidistant intermediate sulci. The anterior margin is trenchant, formed of an enameled keel, in some parts of its length presenting a slightly serrated appearance. Latero-posterior angles rounded and prominent, armed with a double row of small recurved denticles broadly implanted, acutely pointed, separated by about twice their own diameter near the distal extremity, closer towards the base, posterior surface channeled. Base not preserved.

It is a remarkable feature in the specimens composing the genus Acondylacanthus that the basal extremity has not been preserved. There is in every instance where the spines have been described, both American and British, the laconic intimation that the base is unknown.

As already observed this species differs from *A. distans* in the tenuity of its longitudinal ridges and the much finer tuberculation of their surface. It is also a longer spine in proportion to its breadth, and more curved, than *Acondylacanthus distans*.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Acondylacanthus junceus, M'Coy.

(Pl. XLVI., fig. 6.)

Leptacanthus junceus—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd ser., Vol. II., p. 122.
„ „	J. Morris,	1854.	"Catal. Brit. Foss.," p. 332.
„ „	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 288.
„ „	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 633, pl. 3 G, fig. 13.
„ „	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„ „	Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 62.

The specimen described by Prof. M'Coy, as *Leptacanthus junceus*, consists of a small fragment of a spine from the black beds of shale, above the Mountain Limestone of Derbyshire. It appears to be unique, and is in the collection at the Woodwardian Museum, Cambridge. The following is Prof. M'Coy's description of it:— "Nearly straight, about one and a half lines wide; section semi-elliptical; sides gently convex, meeting in front to form a sharp anterior edge, and converging behind to a narrow posterior sulcus, bordered on each side by a row of strong conical downward-curved teeth, little longer than wide, and about the width of their bases apart; each side with about seven longitudinal, narrow, equal, thread-like ridges, twice their diameter apart, and having between each pair two or three obsolete longitudinal striæ." This is included in Leptacanthus rather than in Homacanthus, from the great number and regular delicacy of the ridges.

Formation and locality: Black Shale above Limestone, Derbyshire.

Ex coll. Woodwardian Museum, Cambridge.

Acondylacanthus jenkinsoni, M'Coy.

(Pl. XLVI., figs. 2, 2a.)

Leptacanthus jenkinsoni—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 633, pl. 3 G, figs. 14–16.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	Young and Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., supt., p. 72.
" "	Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 62.

"Fin ray, very long, slender, tapering at the rate of one line in two inches, very much compressed; sides flattened; anterior face surmounted by a strong keel. Sides with about 14–16 ridges, averaging six in two lines; about twenty ridges when six lines wide, and about ten, when two lines wide, (in the latter case near the apex, a smooth band runs along the posterior edge), separated by narrow, shallow sulci; ridges often inconspicuous, and singly interrupted or discontinued at irregular distances; both the ridges and sulci obscured by a longitudinal, slightly irregular striation, posterior edges set with very numerous and very small much-hooked denticles, nearly twice the width of their bases apart, three in three lines, at four lines wide. Length unknown, but upwards of five inches; greatest observed width six lines, at which the thickness is only two lines."—(*M'Coy.*)

Transverse section, the sides are straight, bending over anteriorly, and joining to form a median acutely-pointed carina; posteriorly a shallow sulcus, is bounded by acute latero-posterior angles with denticles. Internal cavity large, sub-lenticular, laterally and anteriorly conforming to the shape of the outer surface, posteriorly produced in the centre, and approaching near to the surface of the posterior sulcus; base, if any, unknown.

The specimens figured by Prof. M'Coy are in the collection at the Woodwardian Museum, Cambridge, and, together with the one now given (Pl. XLVI., fig. 2), form the entire number of specimens known.

This species bears a near resemblance to *A. gracilis* (St. J. and W.); its principal points of difference lie in the more angular form presented in transverse section, and the form of the internal cavity; the posterior denticles are smaller, less frequent, and not so acutely pointed.

Formation and locality: Mountain Limestone, Lowich, Northumberland.
Ex coll. Woodwardian Museum, Cambridge.

Acondylacanthus attenuatus, Davis.

(Pl. XLVI., fig. 3.)

Spine, much compressed, gracefully arched backwards, three inches in length, base imperfect, lowest portion ·3 inch wide, gradually tapering towards the opposite extremity, and ending in a fine point. Anterior surface, with a prominent longitudinal keel, lateral surfaces with 12–14 longitudinal ridges, wider than the intermediate sulci; broad and flat at top, smooth; towards the base the number of ridges increases by bifurcation. A slightly deeper and wider sulcus than the other, passes between the last posterior ridge and the latero-posterior angle. The angle is slightly rounded, and armed with a row of broadly implanted, recurved, sharply-pointed denticles, separated from each other by about their own diameter. Posterior surface hidden by the matrix. Transverse section at part preserved nearest the base, is two and a half times greater in diameter between the antero-posterior margins than between the lateral ones; lateral surfaces converge anteriorly and form an acuminate apex; posteriorly the surface curves inwards, forming on the surface a longitudinal median sulcus, with a row of denticles on each side. Internal cavity, small, oval, placed near the posterior margin, and extending not more than half the diameter of the spine towards the opposite one.

This beautiful specimen appears to be unique. It was presented by the Rev. W. Stokes, with several others, to the Woodwardian Museum, at Cambridge. It presents a more graceful appearance than *A. jenkinsoni,* to which it bears some resemblance, but may be distinguished from it by the comparatively large size of the posterior denticles, and the form of its transverse section and internal cavity.

From *A. colei,* to which it also bears an outward resemblance, it is separated by the roundness and robustness of the spine of *A. colei,* compared with the ovally lenticular, and compressed sides of *A. attenuatus.*

This species offers several points of resemblance with the spine, *Acondylacanthus* (*Leptacanthus*) *occidentalis,* figured by Newberry and Worthen ("Geol. Illinois," Vol. II., p. 116, pl. xii., fig. 2.) but appears to be sufficiently distinguished by the somewhat shallow posterior sulcus, and roundness and robustness of its denticles, those of A. occidentalis being conspicuously furrowed, bordered by two rows of compressed and depressed hooks.

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Woodwardian Museum, Cambridge.

Genus—Asteroptychius, Agass, MS.

Asteroptychius—L. Agassiz, 1833. "Poiss. Foss.," Vol. III., p. 176, indet.
„ F. M'Coy, 1854. "Brit. Palæoz. Foss.," p. 615.

"Bony fin ray, compressed, long, slender, gradually tapering to a point at the distal end, and abruptly tapering at the striated proximate end, or base of insertion; sides moderately convex, converging to the anterior edge, which is strongly keeled; posterior face with a moderate cavity, each lateral edge having a row of small teeth, directed upwards. Surface of the sides with several smooth, thread-like ridges, separated by broader, flat, longitudinally striated spaces, on which are regularly scattered smooth, spinous tubercles"—(*M'Coy.*)

The spines constituting this genus were named by Prof. Agassiz, but were not described. The above description is taken from Prof. M'Coy's "Brit. Palæoz. Fossils," page 615. It is necessary to state, in addition to the above, that the internal cavity is terminal at the base, and not posteriorly open, as in the spines of Hybodonts generally. Several species of Asteroptychius have been described by American palæontologists and in each case the base is unknown; perhaps this may be explained by the fact of the cavity being terminal, and the portion implanted in the body of the fish comparatively short.

Asteroptychius ornatus, Agass.

(Pl. XLVI., figs. 7–9.)

Asteroptychius ornatus—	L. Agassiz,	1837.	"Rech. sur les Poiss. Foss.," Vol. III., p. 176, indet.
„	„	J. E. Portlock,	1843.	"Rept. Geol. Londonderry, &c.," p. 461.
„	„	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 310.
„	„	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 123.
„	„	„	1849.	"Enumerator Palæont.," p. 653.
„	semiornatus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II., p. 118.
„	ornatus—	J. Morris,	1854.	"Catal. Brit. Foss.," p. 318.
„	semiornatus—	„	1854.	„ „ „ p. 318.
„	ornatus—	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 291.
„	semiornatus—	„	1854.	„ „ „ Vol. II., p. 291.
„	ornatus—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 615, pl. 3 K, figs. 23, 24.
„	semiornatus—	„	1855.	„ „ „ p. 616, pl. 3 K, fig. 22.
„	ornatus—	Morris & Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 99.
„	semiornatus—	„ „	1862.	„ „ „ „ Vol. XVIII., p. 99.
„	ornatus—	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 347.
„	semiornatus—	„	1878.	„ „ „ „ p. 347.

Spines, long, tapering, slightly curved, length varying from two to five inches. Specimen 4·5 inches in length, ·4 inch in breadth near the base, tapers gradually and gently upwards to an acute point. Base slightly contracted in width, with finely striated surface. Transverse section triangular, two sides formed by the lateral surfaces which meet anteriorly with an acute angle, posterior surface, one-half the length of each anterior one, forms the base. Internal cavity, medium size, conforming generally in form to that of the outer walls, extends almost to the

apex of the spine; basally, it forms a terminal opening as in the Pleuracanths. A well-defined carina of smooth ganoine extends along the anterior surface of the spine; the sides are ornamented by a variable number of narrow, smooth, longitudinal ridges, which towards the base increase by bifurcation. The ridges are separated by wide flat spaces, along which extend a number of minute longitudinal striæ, and in some of the spaces there is also a row of widely-separated, irregular, smoothly-rounded prominent tubercles, generally restricted to the spaces on the anterior portion of the spine, and occasionally restricted to the space on each side the anterior ridge. The posterior surface is depressed or hollowed, slightly pustulate, with a well developed median ridge. The postero-lateral angles are acute, with a row on each of small acuminate denticles, the points of which are directed upwards.

Paucity of specimens probably led Prof. M'Coy to believe that the form with a single row of tubercles on each side the anterior carina was of sufficient import to render necessary the institution of a separate species. A large series of specimens, however, proves that this is not so, every variety of tuberculation may be traced, and seems to be merely accidental. Specimens are not uncommon in which the several spaces have rows of tubercles, which for this reason would be classed with *Asteroptychius ornatus*, and at the same time have seven or eight, and near the base almost double that number of ridges. All the characters of *A. semiornatus* may be found combined indiscriminately with those of *A. ornatus*, and for this reason they are both here included in the latter, which has priority.

Several species of Asteroptychius have been found in the limestone of Burlington, Keokuk, St. Louis, &c., in Illinois, America.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Compsacanthus, Newberry.

Compsacanthus, Newberry, J. S., "Geol. Survey, Ohio," Vol. I., p. 331.

"Spines, of small size, gently curved backwards; exposed portion smooth and polished; section at all points circular; a single row of relatively large, remote, depressed hooks set along the posterior median line."—(*Newberry.*)

Compsacanthus carinatus, Davis.

(Pl. XLVI., fig. 10.)

Spine, slightly curved, posteriorly imperfect, basal and apical terminations wanting. Portion preserved is 4·3 inches in length, antero-posterior diameter ·65 inch at the part nearest the base and ·4 inch at the opposite end, where the lateral diameter is ·22 inch. In transverse section the spine is elliptical; an internal cavity extends from the base upwards to a short distance from the apex, the basal opening is terminal and wide; the walls of the spine at that portion are thin, and consequently somewhat crushed and fractured; towards the apex the walls are much thicker, and

the internal orifice reduced in diameter. The base was probably short, partaking generally of the character of that of the Pleuracanths. The lateral surfaces are convex and covered uniformly with longitudinal striæ. Anterior surface slightly curved longitudinally: it is produced along the median line so as to form a prominent keel, which extends the whole length of the spine; on each side of the keel there is a deep and broad groove, connecting it with each lateral surface. Posterior surface armed with a single row of recurved, pointed denticles extending the whole length of surface preserved. The denticles are large, broad at the base, tapering rapidly to the point, curved towards the base of the spine.

The genus Compsacanthus was instituted by Dr. Newberry to comprise spines easily distinguished from all others by having a single row of large hooks along the posterior median line. The specimen serving as the type for Dr. Newberry's description was externally smooth and slender, and circular in section. In addition to Newberry's species, two species have been described by the writer, from the cannel coal of the West Riding of Yorkshire ("Quart. Jour. Geol. Soc.," Feb., 1880, p. 62). One of the Yorkshire species is triangular in section the other much compressed laterally: they have in each case a single row of denticles along the posterior surface. In the latter respect all the species agree; but in order that the genus Compsacanthus may embrace all the species so far described it will require some modification of the original description. It may be as well, however, for the present to allow it to remain unchanged; there is the possibility that further discoveries and investigation may show the necessity of new genera for some of the forms of spines with only a single median row of denticles. The species described above rests on a unique example in the Enniskillen collection, which certainly differs very greatly from the type species of the genus, and it is with considerable hesitation that it has been included in the genus.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Cosmacanthus, Agass.

Cosmacanthus, Agassiz, "Poiss. Foss. vieux grès rouge," p. 120.

"Small spines, feebly arched, or almost straight; entire surface ornamented by tubercles disposed in regular, longitudinal series; the most distinct are near the anterior margin of the spine, becoming gradually feebler towards the posterior margin, where they tend to disappear."

Only one species was known to Professor Agassiz from the Old Red Sandstone of Elgin. It was named *Cosmacanthus malcolmsoni.*

Cosmacanthus marginalis, Davis.

(Pl. XLVIII., fig. 3.)

Spine, 2·7 inches in length, basal and apical extremity each imperfect, greatest diameter near base ·35 of an inch, gradually tapers to ·2 at the part preserved

nearest the point; straight: transverse section somewhat triangular, diameter from anterior to posterior surface rather greater than that between the postero-lateral angles. Anterior surface rounded; lateral surfaces slightly depressed, especially towards the postero-lateral angles. The whole of the anterior and lateral surfaces are strongly tuberculated, the tubercles arranged diagonally in parallel rows across the spine; they are large along the front and for two-thirds of the breadth of the sides, the remaining third nearest the back of the spine on each side is covered with minute tubercles without definite arrangement. The larger tubercles are slightly elevated on a bony pedestal, the upper surface thickly coated with ganoine. A deep circular groove extends along the posterior surface. The junction of the posterior and the lateral surfaces is produced to form a broadly rounded angle coated thickly with ganoine, slightly raised here and there into minute tubercles.

This species differs from *Cosmacanthus malcolmsoni*, Ag., from the Devonian rocks ("Poiss. Foss. du vieux grès rouge," tab. 33, fig. 28), in the presence of the thick rounded mass of ganoine which invests each of the latero-posterior angles. From *Cosmacanthus carbonarius*, M'Coy ("Ann. Mag. Nat. Hist.," Second Series, Vol. II., p. 119), described as having the posterior sulcus very wide and rounded "being bounded by the last lateral row of tubercles on each side. A fragment 1 inch 8 lines long and 2½ lines wide at the narrow end, increases at the rate of nearly 2 lines in an inch." This species is distinguished also by the presence of the posterior margin of ganoine, by the shallow posterior sulcus, and its very slight decrease in diameter from the base upwards.

Except that there are no denticulations along the postero-lateral angles, this genus appears to bear a close relationship to that of Lepracanthus (Ag.) from the Coal Measures.

Formation and Locality; Carboniferous Limestone, Armagh
Ex coll. Enniskillen.

Cosmacanthus carinatus, Davis.

(Pl. XLVIII., fig. 4.)

Fin-spine, very slightly curved along anterior margin, posterior straight, 1·5 inches in length, ·15 in greatest breadth at the junction of the base and exposed part. Base tapering. Exposed part ensiform, ending in an acute point. In transverse section the spine is an obtuse-angled triangle, the diameter of the posterior portion being greater than from back to front. The lateral surfaces are thickly covered with ganoine-coated tubercles. The tubercles when magnified present a most peculiar appearance: rising on a stem from the surface of the spine to one and a half times their diameter, they become spread out or extended towards the base of the spine; the surface of the tubercle in this direction is denticulated in

a variety of forms, not unfrequently presenting the appearance ot a hand with extended fingers. The tubercles are not more than one-fiftieth of an inch in diameter, and are devoid of arrangement. The anterior surface is angular and produced in the form of a keel, thickly coated for the most part with bright glistening ganoine. Near the base line the anterior keel is broken into two or three separate tubercles which bear much of the character of those on the sides of the spine, further up the spine the tubercles coalesce and the ganoine extends to the point in constantly increasing thickness and breadth, so that on reaching the apex the ganoine is equal to the whole diameter of the spine, ending in a bluntly rounded point. The posterior surface is deeply channelled by a pulp cavity, extending considerably beyond the basal portion towards the apex. The postero-lateral angles are sharply defined but are devoid of denticles or hooks.

This spine differs materially from the preceding species, to which it bears a superficial resemblance, in the character of its posterior cavity, in the possession of a strong anterior keel of ganoine, and in the tubercles which ornament its sides.

Locality: Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Cosmacanthus carbonarius, M'Coy.

Cosmacanthus carbonarius	—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd ser., Vol. II., p. 119.
,,	,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 323.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 287.
,,	,,	Morris & Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	J. J. Bigsby,	1878.	"Thes. Devon.-Carb.," p 351.

"Spine, nearly straight, semicylindrical; section semilunate; sides and anterior face broadly rounded in one continuous curve, posterior sulcus very wide, rounded; about eight longitudinal rows of small oval tubercles on each side, the tubercles nearly touching in each row, and the rows less than their diameter apart; no posterior teeth, the posterior sulcus being bounded by the last lateral row of tubercles on each side. A fragment, 1 inch 8 lines long and $2\frac{1}{2}$ lines wide at the narrow end, increases at the rate of nearly two lines in an inch."—(*M'Coy.*)

Professor M'Coy remarks that this species differs from the Devonian *C. malcolmsoni,* Ag., in its greater size and much more numerous rows of tubercles. Two imperfect specimens were in the collection of Captain Jones, from Armagh. The specimens from which the above description was written have either become misplaced or lost: they do not appear to be amongst the types which have been preserved from the collection of the late Admiral Jones.

Cosmacanthus priscus, Agass.

(Pl. XLVIII., fig. 1, 2.)

Leptacanthus priscus—	L. Agassiz,	1837.	"Rech. sur les Poiss. Foss.," Vol. III., p. 176, indet.
,, ,,	J. E. Portlock,	1843.	"Geol. Rept. Londonderry, &c.," p. 461.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 306.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 634.
Nemacanthus priscus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist." 2nd ser., Vol. II., p. 120.
Leptacanthus priscus—	J. Morris,	1854.	"Catal. Brit. Foss.," p. 332.
Nemacanthus priscus—	,,	1854.	,, ,, ,, p. 334.
Nemacanthus priscus—	F. J. Pictet,	1854.	"Traité de Paléont," Vol. II., p. 286.
Leptacanthus priscus—	,,	1854.	,, ,, ,, Vol. II., p. 288.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
Nemacanthus priscus—	,, ,,	1862.	,, ,, ,, ,, Vol. XVIII., p. 101.
Leptacanthus priscus—	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 359.
Nemacanthus priscus—	,,	1878.	,, ,, ,, ,, p. 359.

Spine, slightly curved, nearly four inches in length, basal end complete, distal one broken off. It is also split in two along the middle, giving a longitudinal section and exposing the internal canal, which is round and rather more than one-third the diameter of the spine. Towards the base the canal gradually increases in size, the walls becoming thinner near the extremity. The base, one inch in length, is separated from the exposed part of the spine by a diagonal line extending from the anterior margin upwards to the posterior one. The contact of the two sides at an acute angle forms an enamelled keel which extends along the anterior margin. The sides are covered by numerous tubercles without definite arrangement, the intermediate spaces are covered with a reticulated network of minute punctures and lines.

Spines of the genus Nemacanthus occur in the Liassic formations and bear a superficial resemblance to that of Cosmacanthus. Nemacanthus is, however, compressed and oval in section, and only a portion of the lateral surface is covered by tubercles; whilst in Cosmacanthus the section is triangular, with an inclination to roundness. The pulp-cavity is enclosed to a larger extent by the base of the spine, and the surface is almost uniformly covered by tubercles. The posterior margins in Nemacanthus are denticulated, whilst in the genus under consideration there are no denticles.

The species may be distinguished by the round depressed form of the tubercles and the reticulated series of punctures which occupy the spaces intermediate between them, and in the indefinite manner in which the tubercles are arranged on the surface.

Leptacanthus priscus was not described by M. Agassiz, and the genus as defined by Prof. M'Coy (Brit. Palæoz. Fors., p. 633) is quite different to the definition here given of *Cosmacanthus priscus.*

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Geological Society, London.

Genus.—Lispacanthus, Davis.

Spine, medium size, ovate in section, laterally compressed, gradually tapering to a point. Surface entirely smooth. Pulp cavity internal. Base wide, open terminally, walls thin, divided from exposed surface by a very oblique line.

Lispacanthus retrogradus, Davis.

(Pl. XLVIII., fig. 5.)

Spine, from the base upwards the spine is considerably curved posteriorly, and near the apex slightly recurved towards the anterior aspect. It is nearly four inches in length, and its greatest diameter at the base ·4 of an inch. The breadth is gradually reduced towards the apical extremity and ends in a fine point. The line dividing the exposed part of the spine from that imbedded in the body of the fish extends diagonally across the spine in an extremely oblique direction and indicates that the spine extended at a very small angle of elevation along the body of the fish, and in all probability was never raised more than a few degrees. The whole surface of the spine is smooth; anteriorly it is broad, rounded, with a slightly acuminate ridge along the median line. The sides are depressed, having the appearance of a wide and shallow groove extending from the junction of the anterior portion of the exposed part with the base, to within half an inch of the point. The posterior surface possesses a very slight indication of a groove, and leads to the impression that the spine was not connected with a fin. The base is imperfect; it is fibrous and was firmly implanted.

This spine offers several peculiarities which appear to indicate that its relationship was not with the ordinary types. Its connexion with the body of the fish as indicated by the base line, and the absence of a posterior groove for the attachment or accommodation of a fin shows that it was free and possibly only used for offensive or defensive purposes; these characters remove it from the Ctenacanthoid type The base also differs from the Pleuracanth or Chimeroid types, its oblique implantation and wide aperture are quite distinct from the tapering base and almost vertical position of those genera.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Lispacanthus gracilis, Davis.

(Pl. XLVIII., fig. 6.)

Spine, long and tapering, acuminate, gently curved, length five inches, greatest breadth at base ·4 inch, gradually and evenly contracts in diameter to the apex, which is sharply pointed. Transverse section circular, the internal cavity is terminal. Surface of spine is smooth, a very slightly projecting keel extends along the anterior surface. The posterior surface is devoid of denticles, and so far as can be seen of

any sulcus or groove. The portion of base implanted in the body of the fish was small, being ·65 of an inch, equal to about one-eighth the entire length of the spine.

This unique specimen was collected by the late Sir Roderick Murchison, and placed in the Geological Society's museum. Its closest relationship appears to be with Acondylacanthus, N. and W., and Lispacanthus, Davis. It differs from the former in having no surface ornamentation or posterior denticles, though its general contour is similar; and from the latter in the more evenly circular form of the base and spine generally, and also in the absence of the deflexure characteristic of *Lispacanthus retrogradus.*

I propose for the present to place the specimen in the genus Lispacanthus; though not agreeing in all particulars with the characters of that genus, it appears preferable to include it rather than institute a new genus for its especial occupation.

Formation and locality: Mountain Limestone, Kendal Fells, Westmoreland.

Ex coll. Geological Society, London.

Genus.—Dipriacanthus, M'Coy.

Dipriacanthus—M'Coy, "Brit. Palæoz. Foss.," p. 627.

"Spine, small, arched, tapering, much compressed, minutely and irregularly tuberculated; two rows of small conical teeth on the posterior margin, and two rows of larger adpressed teeth on the anterior face directed upwards."—(*M'Coy*).

Prof. M'Coy in the "Annals and Magazine of Nat. Hist.," described two species of Dipriacanthus, viz:—*D. Stokesii* and *D. falcatus.* The only specimen which I have seen of the latter is in the museum of the Geological Society, London. The name attached is in the handwriting of Prof. M'Coy, so that this specimen is probably the one described. It is about one inch in length and possessed of denticles on the posterior margins, but I fail to find any trace of denticulation on the anterior one. As this specimen does not possess the characters distinguishing the genus as defined by M'Coy, it will not be included in the genus. *Dipriacanthus stokesii* is an altogether different specimen with a peculiarly expanded base which does not conform to any ordinary forms. It resembles to some extent the shorter branch of Cladacanthus, but with the present limited knowledge of the form, being restricted to a single specimen, it may not be advisable to remove it.

Dipriacanthus stokesii, M'Coy.

(Pl. XLVIII., fig. 10.)

Dipriacanthus stokesii—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd ser., Vol. II., p. 121.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 325.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 292.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 627, pl. 3 K, fig. 18.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 355.

"Spine, slightly arched, much compressed, sides flat, anterior and posterior margins narrow, obtusely rounded; section oblong, the long diameter being four to five times longer than the short; teeth of the posterior margin slender, conical, projecting at right angles to the spine; teeth of the anterior margin large, thick, smooth, the upper sharp edge widest, closely adpressed to the surface; surface closely covered with small irregular smooth granules, which under a strong lens are found to be radiatingly striated at their base, and with the intervening narrow spaces very minutely granulated.

"When highly magnified the granulation of this spine resembles on a small scale the star-like style of ornament of the bony plates of Asterolepis (Eich). The base is imperfect, but apparently dilated in a remarkable degree, and in its present state the lower portion seems bent at a considerable angle from the curve of the rest of the spine"

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Woodwardian Museum, Cambridge.

Genus.—Homacanthus, Agass.

Homacanthus—Agass, "Poiss. Foss. Vieux Grès Rouge," p. 113.
„ M'Coy, "Brit. Palæoz. Foss.," p. 632.

"Fin-spine, small, rather rapidly tapering, moderately arched backwards; sides flattened, converging to the anterior face, which is obtusely keeled; sides covered with few very coarse, longitudinal ridges, and fine striæ in same direction; posterior margin with two rows of denticles arched downwards"—(*M'Coy*). Base comparatively large, with external cavity open posteriorly.

Homacanthus microdus, M'Coy.

(Pl. XLVIII., figs. 7–9.)

Homacanthus microdus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II., p. 115.
„ „	J. Morris,	1854.	"Catal. Brit. Foss." p. 329.
„ „	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 288.
„ „	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 633, pl. 3 K, fig. 19.
„ „	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„ „	Armstrong, Young, & Robertson,	1872.	"Catal. West. Scot. Foss.," p. 62.
„ „	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 357.

Spine, slender, arched posteriorly, length 2·0 inches, the base occupying one-fourth the entire length. Breadth at junction of base and exposed surface ·2 of an inch, thence it gradually tapers to a fine point, base slightly attenuated. Transverse section triangular. Lateral surface with two or three longitudinal ridges, enameled and broad. Intermediate hollows wide and deep, flat at the bottom with, in some instances, a second series of minute longitudinal striæ. Anterior margin formed by a broad enameled keel extending from the base to the apex. Posterior surface

hollow, basal portion forming a deep sulcus from which an internal cavity extends upwards towards the superior extremity. Each latero-posterior angle is armed with a row of recurved broadly-implanted, rapidly-tapering, finely-pointed teeth rather widely separated, especially on that portion nearest the basal sulcus.

A second specimen, representative of others, is almost straight, shorter, and wider in proportion to its length than those just described. In other respects it is very similar. It possibly occupied a position in front of the second dorsal fin, whilst the longer and more curved specimens may have been similarly placed before the first dorsal fin, as in the existing Acanthias.

The description of Homacanthus given by Prof. M'Coy was from a very imperfect but at the time unique specimen. There is in the Enniskillen collection a considerable series, which has led to modifications of, and additions to, the description given by Professor M'Coy.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Homacanthus macrodus, M'Coy.

(Pl. XLVIII., fig. 14.)

Homacanthus macrodus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II., p. 115.
" "	J. Morris,	1854.	"Catal. Brit. Foss.," p. 329.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 288.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 632, pl. 3 K, fig. 20.
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
" "	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 357.

"Spine, about eight lines long and two lines wide at the base, slightly arched and tapering to a point, section compressed, trigonal, anterior face formed by a narrow rounded keel; posterior concave face bounded on each side by a large rounded ridge, between which and the anterior keel there is on each side a still smaller rounded longitudinal ridge; the two posterior ridges on each side dichotomize near the base of the two intervening spaces, the anterior is rather wider and the posterior rather narrower than the ridges, which they separate; they are concave and very finely striated longitudinally; posterior face with twelve or fourteen very large compressed falcate teeth, alternating in two rows, the alternating bases touching, keeled on their convex edge, their length nearly equalling the width of the side of the ray at their base."

This spine is distinguished from the last, *H. microdus*, M'Coy, by the absence of striæ in the sulci between the ridges, in the different arrangement of the longitudinal ridges, and the large falcate teeth which extend along the posterior angles. The latter characteristic and the less numerous ridges, distinguish it from *H. arcuatus* Ag., of the Old Red Sandstone.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Woodwardian Museum, Cambridge.

Genus.—Gnathacanthus, Davis.

Spine, triangular in section, long, and tapering. Lateral surfaces compressed with five or six longitudinal ridges, sometimes with intermediate rows of smooth, enameled tubercles. Anterior margin formed by the conjunction of the two lateral surfaces, forming an acute angle, armed with widely spaced denticles one-third the diameter of the spine in length, apex of denticles sculptured. Between the larger denticles are several smaller ones possessing similar characters. Posterior surfaces concave, wide, smooth or finely punctate with a slight median ridge. Postero-lateral angles sharp and well-defined, minutely and closely tuberculated. Internal pulp cavity large, conforming roughly to the external configuration of the spine.

This spine bears a somewhat close resemblance to those of the genus Gampsacanthus, St. J. and W. ("Palæon. of Ill.," Vol. VI., p. 471), and especially to the species *G. typus* of the same authors (*op. cit.* p. 472, pl. xxii., fig. 12). It differs mainly, and to all appearance essentially in the character of the posterior surface and the angular junction of the postero-lateral surfaces. In Gampsacanthus the posterior surface is occupied by large, laterally compressed, subtrenchant denticles, slightly curved downwards, widely spaced, and of nearly uniform size. The lateral surface of the spine curves gradually to the base of these denticles. In the Armagh specimens, on the contrary, the postero-lateral angles are sharp and form ridges along which there are minute tubercles, whilst the posterior surface is broad, concave and smooth, with a slight median ridge but no denticles.

The only spine at all resembling this one from British strata hitherto described is the Dipriacanthus of M'Coy ("Brit. Palæoz. Foss.," p. 627, pl. 3, K., fig. 18), and it only approaches it in the possession of denticles along the anterior margin; it is quite distinct in form and general outline.

Gnathacanthus triangularis, Davis.

(Pl. XLVIII., fig. 11.)

Spine, imperfect; length preserved 1·75 inches, greatest breadth ·35. inch. Both the basal and apical extremities are wanting and it is an uncertain approximation that the spine may have been four and a half to five inches in length. In transverse section the spine is triangular, the base, formed by the posterior aspect being half the length of the two sides, and the apex or anterior portion forming an acute but somewhat rounded angle. The lateral surfaces are straight or slightly depressed; they are divided into six or seven rows of raised, pustulate, enamel-coated tubercles, circular in form and extending longitudinally along the surface; the tubercles appear to have been only superficially implanted, many of them having been removed, leaving a hollow space to mark their former position. Between each row of tubercles there is a small ridge extending parallel with them. Anterior

surface rounded and narrow, studded with denticles of two sizes, the larger are about ·35 inch apart and extend ·1 inch from the surface, inclining slightly towards the apex of the spine. The basal portion of the denticle is round and smooth; The apex acuminate, with a series of minute ridges extending from the point downwards. Between each of the large denticles there are three or four smaller ones, resembling the larger ones in miniature. Posterior surface slightly concave, fibrous, minutely and irregularly pitted, with a median ridge, small but well-defined. The postero-lateral angles are closely studded with minute enamel-tipped tubercles. The internal orifice is large, partaking generally of the external form of the spine. Whether it formed an external sulcus at the basal portion of the spine, or was enclosed with a terminal opening only, the spine is not well enough preserved to show.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Gnathacanthus striatus, Davis.

(Pl. XLVIII., fig. 12.)

Spine, imperfect; base wanting, part preserved 1·6 inches in length, greatest breadth ·3 inch, at basal extremity. Slightly curved posteriorly, gradually tapering towards the superior extremity which terminates acutely. Transverse section, triangular, the sides meeting at an acute angle to form the anterior margin, base shorter than sides, internal cavity large and oval. Lateral surfaces ornamented by a series, six or eight, of longitudinal, enamelled, strong, inosculating ridges. The anterior margin is occupied by a row of closely-implanted compressed denticles, wide at their base, curved downwards, and sharply pointed. Each of the latero-posterior margins also possesses a line of denticles, smaller and finer than the anterior ones, also curved downwards and separated from each other by about double their own diameter.

The species differs from the previous one in its less decidedly triangular form and more especially in the ornamentation of its sides. The pustulate enamel-coated tubercles of *G. triangularis* are replaced by a much more decided series of ridges than occurs in that species. The anterior row of denticles and the general form of the spine, however, are sufficiently characteristic to render its genuine position undoubted.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Cladacanthus, Agassiz. MS.

Cladacanthus—L. Agassiz, 1833. "Poissons Foss.," Vol. III., p. 176. (MS.)
Erismacanthus—M'Coy, 1848. "Ann. Nat. Hist.," 2nd ser., Vol. II., p. 119.

"Spine, of three divaricating portions; first, a large, compressed, finely striated base, which entered the flesh; secondly, a short, strongly compressed, rapidly tapering

spine, curved directly backwards, the sides marked with strong, smooth, longitudinal ridges, and having two rows of short, downward-curved teeth on the posterior concave margin ; thirdly, a peculiar prop-like portion extending directly forward nearly at right angles with the base, gently arched downwards, compressed at the basal half, depressed at the distal half, closely covered with blunt, smooth, oval tubercles, and with some large irregular spines on the under side ; the portion of the base above the flesh, and from which these two portions branch, is irregularly tuberculated."—(*M'Coy.*) The anterior portion of the spine terminates in an enlarged process studded with four or five terminal tubercles of larger size than on any other portion of its surface.

This very peculiar ichthyodorulite was first named by Prof. Agassiz and recorded without description in the " Poissons Fossiles." The specimens were in the collection of the Earl of Enniskillen, at Florence Court, where they have remained to the present time. Prof. M'Coy afterwards described specimens of the same genus and species, which he found in the collection of Capt. Jones, R.N., in the "British Palæozoic Fossils" as *Erismacanthus jonesii.* Priority being generally accepted as the guide in the retention of synonymical names, in the present instance the generic name of Agassiz, viz., Cladacanthus, must be adhered to.

Cladacanthus paradoxus, Agass. (indet.)

(Pl. XLVII., figs. 1–5.)

Cladacanthus paradoxus—	L. Agassiz,	1837.	" Rech. sur l. Poiss. Foss." Vol. III., p. 176 (indet).
" "	C. G. Giebel,	1848.	" Fauna der Vorwelt," Vol. I., pt. 3, p. 310.
" "	H. G. Bronn,	1848.	" Nomencl. Palæont.," p. 303.
Erismacanthus jonesii—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II., p. 119.
Dipriacanthus falcatus—	"	1848.	" " " " 2nd ser., Vol. II., p. 121.
Cladacanthus paradoxus—	H. G. Bronn,	1849.	" Enumerator Palæont.," p. 653.
" "	J. Morris,	1854.	" Catal. Brit. Foss.," p. 321.
Dipriacanthus falcatus—	"	1854.	" " " p. 325.
Erismacanthus jonesii—	"	1854.	" " " p. 326.
" "	F. J. Pictet,	1854.	" Traité de Paléont.," Vol. II., p. 293.
Dipriacanthus falcatus—	"	1854.	" " " Vol. II., p. 292.
Erismacanthus jonesii—	F. M'Coy,	1855.	" Brit. Palæoz. Foss.," p. 628, pl. 3 K, figs. 26, 27.
Cladacanthus paradoxus—	Morris & Roberts,	1862.	" Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
Dipriacanthus falcatus—	" "	1862.	" " " " Vol. XVIII., p. 100.
Erismacanthus jonesii—	" "	1862.	" " " " Vol. XVIII., p. 100.
" "	St. John & Worthen,	1875.	" Palæont. of Illinois," Vol. VI., p. 463.
Cladacanthus paradoxus—	J. J. Bigsby,	1878.	" Thesaurus Devon.-Carbonif.," p. 349.
Dipriacanthus falcatus—	"	1878.	" " " p. 355.
Erismacanthus jonesii—	"	1878.	" " " p. 355.

The following description of this spine is taken from the admirable one given by Prof. M'Coy, with some modifications rendered necessary by the observation of a large suite of specimens in the Enniskillen and other collections.

"Posterior spine, three times as long as wide, breadth near its attachment maintained for about one-third its length, remaining two-thirds rapidly contracted, deeply curved, and ending in a fine point. Sides much compressed with a variable number, four to nine, of longitudinal ridges, which are smooth and less than their own diameter apart, the intervening spaces occasionally longitudinally striated ; along the anterior margin there is a well-defined carina ; posterior concave surface with two regular close rows of small pointed denticles, directed obliquely downwards ; the surface towards the base is marked by small, scattered, oval, smooth tubercles, anterior branch more than twice the length, and about the same size at its origin, as the posterior one ; a transverse section shows the height of the anterior branch to be double its width at the basal half, but it becomes depressed, so that its width is double the height in a section of the distal half; an internal cavity extends almost to the distal extremity, it is large compared with the diameter of the spine ; it is covered above and on the sides with close quincuncially arranged, smooth, oval tubercles ; near the extremity the spine becomes abruptly expanded and is covered with tubercles of much larger size, the extremity is generally curved downwards ; the basal part of the spine from which the two branches take their origin is equal to the width of their united bases, this is maintained for a short distance downward, after which the base becomes expanded to one and a half times its diameter above. The upper part is covered with smooth, rounded, shining tubercles, scattered indiscriminately ; lower, the base is much compressed and finely striated. with an abruptly truncated termination.

The length of the base is 1·4 inch, its width at bottom 1·1 inch, near the top ·7 inch. The length of the posterior portion of the spine is 1·5 inches and that of the anterior 3·2 inches.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Cladacanthus major, Davis.

(Pl. XLVII., figs. 6, 7.)

Fragments of a second species of this peculiar genus of fish-remains occur at Armagh and may be consulted in the Enniskillen collection. They consist of portions of the long anterior part of the spine and include one example showing the extremity of this portion of the spine. By comparison with *C. paradoxus*, Ag., this one was about three lines larger. The anterior portion of the spine which is preserved is much compressed. Its lateral surfaces are covered with circular tubercles arranged in lines roughly parallel to the anterior margin. The tubercles are individually covered with minute dots or punctures only observable when highly magnified. The greatest breadth of the part of the spine preserved is ·65 of an inch and at that point there

are eleven rows of tubercles on one side. The walls of the spine are thin and it appears to be owing to this that they are so much compressed. The diameter between the sides is little more than one-fourth that between the anterior and posterior margins. The anterior margin is formed by a strong carina of shining ganoine, ·1 of an inch across. The posterior one is not well defined but appears to have been devoid of denticulations.

Another specimen exhibits the extremity of the longer branch of the spine, an impression is preserved a little over two inches long, the extremity is well preserved and exhibits somewhat similar peculiarities to that of *C. paradoxa*, Agass. The diameter of the stem of the spine taken from the impression on the matrix is ·4 of an inch: half an inch from the extremity the spine becomes suddenly expanded to ·9 of an inch. At its distal end it is divided into four toe-like prolongations, each of which is covered by a single large plate of ganoine, oval in form and ·2 of an inch across the longer diameter. The body of the spine was coated with enamelled plates of unequal size averaging ·1 of an inch across, and without definite arrangement.

This species is distinguished from *Cladacanthus paradoxus* by its much larger size.

Locality: Mountain Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Physonemus, Agass. MS.

Physonemus—Agassiz, L., 1833. "Poiss. Foss.," p. 176, MSS.
,, M'Coy, F., 1855. "Brit. Palæoz. Foss.," p. 638.

"Fin spine, much compressed, with a variable backward curvature; base of insertion large; posterior edge with two rows of small denticles. Surface covered with very numerous cord-like longitudinal ridges, which swell at short regular intervals into small bubble-like tubercles."—(*M'Coy*).

Professor Agassiz named the spines of this genus. Professor M'Coy formulated the description, from which the above is taken.

Physonemus arcuatus, M'Coy.

(Pl. XLVII., fig. 8.)

Physonemus arcuatus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II. p. 117.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 338.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 291.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 638, pl. 3 I., fig. 29.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus-Devonico.-Carb.," p. 363.

"Spine, slightly imperfect at the distal extremity, probably half an inch missing —remaining portion 5·5 inches in length along the convex surface. Two-thirds the length of the spine was exposed, the remaining third was embedded in the body

of the fish. The line separating the two parts extends obliquely from the convex to the concave surface, with apparently the contrary direction usually observed on fish-spines. The inner or concave margin, which was probably the posterior one, was less deeply implanted in the integuments than the anterior one. The curvature of the anterior margin forms the arc of a circle exceeding one-third its circumference; its greatest diameter is ·9 inch at the junction of the base with the exposed surface. The base is large and expanded, more or less bilobate, much compressed. The exposed portion gradually tapers towards the point, and if perfect would probably terminate acutely. The lateral and anterior surfaces are covered by numerous rounded longitudinal ridges, "less than their own diameter apart, dilated into rounded, smooth, bubble-like tubercles, which are nearly twice their diameter apart; some of the tubercles occasionly flattened and transversely oblong; the narrow sulci between the ridges have usually two or three obscure longitudinal striæ; on the posterior edge are two irregular alternating rows of obtusely pointed tubercles, finely stellated by radiating striæ at base, and about one line in diameter."

A large and massive spine, *Physonemus gigas*, N. and W., a foot or more in length, and two inches in diameter has been described by Messrs. Newberry and Worthen (" Geol. Survey of Illinois," Vol. VI., p. 373. pl. ii., fig. 1). It is from the Burlington Limestone, and very closely related to *Physonemus arcuatus*, M'Coy; its large size and an obliquely conical form of the stellate posterior tubercles being the only differences. The authors named above, consider that the curvature of the spines of this genus is reversed, the concave surface being the anterior one and *vice versa*; the correctness of this supposition is very doubtful and it appears most probable that the spine is bent backwards in the ordinary manner, the denticles are extended along the concave surface, and there is a decided groove between the two rows in some of the specimens. The diverse obliquity of the line of demarcation between the basal and upper portions of the spine, may easily be accounted for by the form of the spine, and is such as would naturally accrue from its great curvature.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Physonemus subteres, Agass. MS.

(Pl. XLVII., fig. 12.)

Physonemus subteres—	L. Agassiz,	1837.	"Rech. sur l. Poiss. Foss.," Vol. III., p. 176, indet.
,, ,,	J. E. Portlock,	1843.	"Rept. Geol. Londonderry, &c.," p. 461.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 310.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 972.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 653.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 338.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 291.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 638, pl. 3, I., fig. 30.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc." Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus, Devonico-Carb.," p. 363.

This species, like many others, was named by Prof. Agassiz but left undescribed. A specimen, which very doubtfully belongs to this genus, is figured in M'Coy's "Brit. Palæoz. Foss.," p. 638, pl. 3 I, fig. 30. It is described as "a fragment five lines long, straight, without perceptible tapering, one and a half lines wide, about four ridges in the space of one line; the intervening spaces being rather wider than the ridges themselves, which swell at alternate intervals into oval, smooth tubercles, about their own diameter apart: intervening spaces with about three longitudinal punctured striæ. The species is easily distinguished from the *P. arcuatus* by its small dimensions, slender tapering form, and straightness; two small rows of teeth on the posterior side."

The original specimen, named by Prof. Agassiz, *Physonemus subteres,* is in the Jones' collection at the Geological Society. It is 2·0 inches in length and less than a quarter of an inch in diameter. The specimen is imperfect at each end, and the portion preserved is in great part embedded in the matrix. The sides are covered with a series of longitudinal ridges with intermediate hollows about the same diameter as the ridges. The latter are coated with enamel and are, at intervals, slightly produced so as to form a bead-like irregularity of the surface. The posterior surface, which is in part exposed, is hollowed into a longitudinal groove. The angle formed by the side and back of the spine is devoid of denticulations.

The specimen does not present the characteristic features of the genus Physonemus as defined above. It has far more the appearance of a Ctenacanthus, but in default of better preserved examples it is perhaps premature to remove it to that genus. It may have been a portion of a long spine like the one figured of *P. attenuatus.*

Formation and locality: Mountain Limestone, Armagh.
Ex. coll. Geological Society, London.

Physonemus attenuatus, Davis.

(Pl. XLVII., fig. 10.)

Spine, broad and strong near the base, rapidly tapering and acuminate towards the superior extremity. It is six inches in length along the outer curvature. The exposed portion of the spine is imperfect, and in great part broken away. The surface was striated longitudinally. The base gradually expanding downwards is widest at the extremity being 1·5 inches, and apparently produced on its posterior surface to form an acute angle, this appearance however, may be due to imperfection in its preservation. The internal cavity is large near the base of the spine but becomes very small towards the point, and terminates before reaching it.

This species is very distinct from any hitherto described. Its long attenuated form, and the peculiar expansion of the basal region renders its determination easy.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Physonemus hamatus.

(Pl. XLVII., figs. 9, 11.)

Onchus hamatus—	L. Agassiz	1837.	"Rech. sur les Poiss. Foss.," Vol. III., p. 9, pl. 1, figs. 7, 8.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 302.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 843.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 652.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 334.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 284.
,, ,,	Morris, & Roberts,	1862.	"Quart. Journ. Geol. Soc." Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus, Devonico-Carb.," p. 359.

Prof. Agassiz described this form as a species of Onchus in the following terms: "It is distinguished from all other Ichthyodorulites by its strong curvature, which forms almost a semicircle. It rapidly tapers towards the point; the base is simply but strongly indented and the internal cavity does not appear to extend the whole length of the spine . . . . . The surface is finely striated and the striæ are smooth."

The genus Onchus is described as composed of species resembling the Lias Hybodonts in all respects except that the posterior denticles are absent and the species are generally small in size. One species (*O. hamatus*) differs from the remainder in its peculiar form and want of ornamentation, and Prof. Agassiz, whilst leaving it provisionally in the genus Onchus, expresses an opinion that it may be necessary to constitute a new genus for its accommodation.

Though this species differs in some respects from the type in Prof. M'Coy's definition of the genus, notably in its want of surface ornament, its general form so nearly approaches to Physonemus that it may be safely transferred from the genus Onchus to occupy a position so much more congenial.

Several specimens of this species occur in the collection of the Earl of Enniskillen, and also in the Museum at Bristol. They are all from the Black Rock limestone of Bristol whilst all the specimens of *Physonemus arcuatus* and *P. subteres* have been found in the limestone of Armagh.

Formation and locality: Mountain Limestone, Bristol.
Ex coll. Earl of Enniskillen.

Genus—Chalazacanthus, Davis.

Spine, medium size, strong, curved, tapering to a point, laterally compressed. Base large, striated, open posterior cavity, which higher up is enclosed. Base separated from the exposed portion by an oblique line. Surface of upper part ornamented by tubercles devoid of definite arrangement.

This spine bears some resemblance to those of the genus Drepanacanthus N. and W., and Xystracanthus, Leidy ("Proc. Acad. Nat. Science, Phila.," 1859), but

if the diagnosis of these genera be correct, it is at once distinguished by the direction of the line dividing the base from upper part of the spine, which in Drepanacanthus ("Geol. Surv. Illinois," Vol. II., p. 121) "slopes upward at an angle of 45° from the concave to the convex margin," so that the spine must have had an inclination forwards instead of backwards. In the genus at present described the spine was inclined in the ordinary way, backwards.

In the "Fauna du Calcaire Carbonifere de la Belgique," L. G. de Koninck describes a genus Stichacanthus. In many respects it appears to be closely related with this, but it differs in having all the tubercles arranged in longitudinal lines and attached, the one to the other, by a prolongation of the surface; they have also the posterior border armed with a row of small oblique teeth directed towards the base. Mons. de Koninck states that there is a specimen of this ichthyodorulite at the British Museum. I have not observed, during recent visits to the collections at Cromwell-road, such a specimen as he describes.

Chalazacanthus verrucosus, Davis.

(Pl. XLVIII., fig. 13.)

Spine, about six inches in length, and less than one inch wide at its greatest breadth midway between the two extremities, moderately curved, the anterior margin more so than the posterior, the two somewhat rapidly converging near the apex. Transverse section triangularly cone-shaped, sides much compressed and about twice the length of the base, latter hidden by matrix, the two sides meet anteriorly and form an obtusely rounded surface without keel; the basal portion of the posterior surface forms a deep cavity; higher it is enclosed and extends nearly the whole length of the spine. Base imperfect, slightly tapering, osseous, striated. Length along the anterior margin 1·8 inches, and about three inches posteriorly. Line dividing the basal from the exposed part decidedly oblique with convex curvature towards the base. The striated character of the base is continued some distance along the posterior margin. Exposed surface ornamented by a large number of tuberculations without definite arrangement, occasionally forming into oblique rows, at other places longitudinal ones; the tubercles are less distinct near the apex of the spine.

A second specimen, in the Enniskillen collection, probably belongs to this species, it is imperfect and indistinct, but appears to conform generally to the description given above. In transverse section it is much less compressed laterally, and the external tuberculation is more prominently developed. It is from the Mountain Limestone of Armagh.

Formation and locality: Lower Carboniferous Limestone, Black Rock, Avon, Bristol.
Ex coll. British Museum.

Genus Cladodus, Agass.

Cladodus—Agassiz, 1833.	"Poiss. Foss.," Vol. III., p. 196.
,, M'Coy, 1855.	"Brit. Palæoz. Foss.," p. 619.

"Teeth, with a broad, horizontal, semicircular, thick, bony, coarsely-fibrous base, rounded behind, truncated in front; crown divided into long, sharp, subulate, conical points, arranged along the straight truncated edge of the base; medial cone much larger than the secondary ones, of the latter the external cones are largest; all the cones striated longitudinally, and either circular in section or with simple cutting edges, slightly compressed."—(*M'Coy*).

In Prof. Agassiz's definition of the genus all the characters pertaining to the base are omitted. He points out the great resemblance existing between the teeth of Cladodus and those of Hybodus of the more recent Lias formations. There is the same slender form of the median cone and foldings of the enamel—the same relations between the root and the crown. The median cone in both is flanked on each side by secondary cones, but with this difference, that instead of decreasing in size from the median cone, towards the lateral extremities, they present an inverse disposition, the largest secondary cones being situated at the extremity of the base and diminishing in size towards the median one.

So far as known, all the species of Cladodus are confined to the Carboniferous rocks, so that they may be looked upon as the forerunners of the genus Hybodus, which makes its appearance in the rocks of Triassic age.

Cladodus mirabilis, Agass.

(Pl. XLIX., figs. 1–5.)

Cladodus mirabilis—	Agassiz, L.	1833.	"Poissons Foss.," Vol. III., p. 197, pl. 22 B, fig. 9–13.
,, ,,	Portlock, J. E.	1844.	"Geol. Report, Fermanagh, &c.," p. 461.
,, ,,	Giebel, C. G.	1858.	"Fauna der Vorwelt," Vol I., pt. 3, p. 322.
,, ,,	Pictet, F. J.	1854.	"Traité de Palæont," Vol II., p. 258.
,, ,,	M'Coy, F.	1855.	"Brit. Palæoz. Foss.," p. 619.
,, ,,	D'Eichwald, E.	1861.	"Lithea Rossica," p. 1604.
,, ,,	Morris & Roberts,	1862.	"Quart Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	Rowanowsky, H.	1864.	"Bull. de la Soc. Imper. des Nat. de Moscou," Vol. XXXVII., p. 166, pl. iv., fig. 31.
,, ,,	Young & Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., supt., p. 69.

Teeth vary considerably in size and form. Base semicircular, very thick and coarsely osseous, extending more or less horizontally at right angles to the cones forming the crown. The under side of the base is concave in the centre, the root of the crown conforming to, and laying parallel above it. Crown consists of central cusp and an irregular number of bilateral secondary ones, usually two on each side. The median and secondary cones are thick, circular and strongly attached to the base, abruptly tapering and ending in a more or less acuminate apex slightly inclined backwards. The lower portion of each cone is deeply but finely striated,

the ridges becoming obliterated, especially in large and mature teeth, towards the summits. A large example measures 1·5 inches across the base; the latter extending in a semicircle ·75 of an inch backwards. Height of median cone ·9 inch, width at base ·4 inch. There are three lateral cones on each side, the outermost largest. In other specimens the median cone is considerably thicker and more robust, and there are generally two cones only on each side of the principal one. They are more or less cylindrical and devoid of cutting edge.

This species was regarded by Prof. Agassiz as the type of the genus. A magnificent series exists in the Enniskillen collection from which the beautiful teeth, on Plate XLIX., have been selected.

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Cladodus marginatus, Agass.

(Pl. XLIX., figs. 7–9.)

Cladodus	marginatus—	Agassiz, L.	1838.	"Poiss. Foss.," Vol. III., p. 198, pl. 22. B, fig. 18–20.
„	lævis—	M'Coy, F.	1848.	"Ann. Nat. Hist," 2nd ser., Vol. II., p. 133.
„	marginatus—	Portlock, J. E.	1844.	"Geol. Rept. Londonderry, &c.," p. 461.
„	„	Giebel, C. G.	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 323.
„	„	Pictet, F. J.	1854.	"Traité de Palæont," Vol. II., p. 258.
„	lævis—	„	„	„ „ „ Vol. II., p. 258.
„	„	M'Coy, F.	1855.	"Brit. Palæoz. Foss.," p. 619, pl. 3 K, fig. 5.
„	marginatus—	„	„	„ „ „ p. 619.
„	„	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
„	lævis—	„	„	„ „ „ „ Vol. XVIII., p. 100.
„	„	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., supt., p. 69.

Teeth, base, strong, broadly expanded, concave, fitting to the base of the crown. Crown, median cone large, thick and strong, generally inclined at an oblique angle to the base, obtusely pointed, somewhat compressed, with a raised cutting edge along each side, surface finely striated in specimens not greatly worn. Two secondary cones on each side, terminal cones divaricating, slightly larger than the intermediate ones, short, broadly expanded at the base, obtuse, striated same as the median cone.

Several specimens are much worn by using, the cones being reduced to a short stump. In such instances every trace of the surface striation is removed and the teeth present a perfectly smooth appearance. The smooth teeth were considered by Prof. M'Coy as separate species, whilst *C. marginatus,* he included in the species *C. mirabilis,* Ag. In both these determinations there can be little doubt that Prof. M'Coy erred. *Cladodus marginatus* as defined by Prof. Agassiz is quite distinct from *C. mirabilis* of the same author, no amount of wearing would reduce the long, cylindrical, distinctly-separated lateral cusps of the latter to the form presented by the former, in which the cusps are united together by their bases. In all particulars

the *C. lævis*, M'Coy, agrees with the much-worn, smooth specimens of *C. marginatus* given above.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Cladodus elongatus, Davis.

(Pl. XLIX., figs. 10, 11.)

Teeth, large, very prominent median cone, variable number of lateral cones, those placed externally considerably the largest. Base large and expanded, subelliptical, more or less rounded behind; anterior margin straight with the exception of the median portion which is curved inwards, rounded at the extremities, moderately thick, diminishing in thickness backwards, lateral diameter of base 1·6 inches, from front to back, ·7 inch. Median cone 1·3 inches in height with sigmoidal curvature ·3 of an inch wide at base, that width being maintained with very slight diminution one half the height, it then tapers gradually and terminates, in specimens not much worn, in an acutely pointed apex; transverse section, subtriangular; anterior surface slightly convex, laterally produced so as to form a cutting edge; posterior surface deeply convex, with median angularity towards the apex; anterior and posterior surface uniformly striated. Lateral or secondary denticles number five on each side. The two external ones are large, firmly implanted, accuminate, striated similarly to median one; they are ·45 inches in length slightly and sigmoidally curved with points deflected outwards. Intermediate cones small, equidistant, ·15 of an inch long. In addition to the more prominent denticles indicated, there are, in very well preserved specimens, others very minute and apparently interspersed without definite arrangement.

This species is distinguished by its largely expanded, flat base, and the peculiarly long and graceful proportion of the median tooth. In general form it most nearly approaches *Cladodus striatus*, Ag., from Tynan in Ireland; it differs from that species in the characters just indicated. This species also bears some resemblance to examples found in the lower Kinderhook fish-beds of Illinois, especially *Cladodus alternatus*, St. J. & W., ("Geol. Surv. Ill.," Vol. VI., p. 265, pl. 2, figs. 14–18. This may be distinguished, however, by the alternate secondary denticles being of unequal length, and its smaller size. *C. grandis*, N. & W. ("Geol. Surv. Ill.," Vol. II., p. 29 pl. I., fig. 15), similar in form, is separated by its compressed form of median cone and the irregular arrangement of the secondary ones.

Formation and locality, Mountain Limestone, Richmond and Settle.
Ex coll. Reed collection, York Museum.

Cladodus striatus, Agassiz.

(Pl. XLIX., figs. 12, 13.)

Cladodus striatus—	Agassiz, L.	1838.	"Poiss. Foss.," Vol. III., p. 197, pl. 22 *b.*, fig. 14–17.
,, ,,	Portlock, J. E.,	1844.	"Geol. Rept. on Londonderry, &c.," p. 461.
,, ,,	Giebel, C. G.,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3., p. 323.
,, ,,	Bronn, H. G.,	1848.	"Nomencl. Palæont.," p. 305.
,, ,,	Pictet, F. J.,	1854.	"Traité de Paléont.," Vol. II., p. 258.
,, ,,	Morris, J.,	1854.	"Cat. Brit. Foss.," p. 322.
,, ,,	M'Coy, F.,	1855.	"Brit. Palæoz. Foss.," p. 620.
,, ,,	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc. London," Vol. XVIII., p. 100.
,, ,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supplement, p. 69.
,, ,,	De Koninck, L. G.,	1878.	"Fauna du Calc. Carb. de la Belgique."

Teeth, base semicircular, large, moderately thick, and undulated at the rounded edge with a few obtuse, irregular, radiating furrows below, and obscurely nodose above. Width 1 inch to 1·25 inches broad, from middle of flat side to middle of convex margin ·5 inch. In front, the base joins to the crown with a median sinus the junction being marked by an overlapping ridge. Crown; median cusp long, comparatively slender, moderately compressed, in a few instances slightly sigmoidal flexure, in others nearly straight or slightly curved backwards. Lateral edges smooth and sharp; the anterior and posterior surfaces of the cusp striated more closely than in other species, apex smooth and sharply pointed.

Lateral cones, six or more on each side, of irregular size, but very small, terminal ones larger, ·2 to ·3 of an inch long, and ·1 of an inch wide at the base, pointed outwards, in addition to the secondary cones there is frequently a number of still smaller projections interspersed indiscriminately—they are only seen, however, in well preserved specimens.

The distinguishing characters of this species is to be found in the large number of small lateral cones or cusps, and the more than usually deeply striated surface of the median one.

The teeth comprised in this species do not bear more than a generic resemblance to any of the previously described British species. Three or four species described by Messrs. St John and Worthen, from the fish-beds of the Kinderhook Limestone at Burlington, Iowa, appear to be similar in form and to possess near relationship with them. Amongst the American species, *Cladodus wachsmuthi*, St. J. and W. ("Palæon. Ill.," Vol. VI., p. 263, pl. 3, figs. 1–7); *C. succinctus*, St. J. and W. (*op. cit.*, p. 265, pl. 3, figs. 8–12); *C. alternatus*, St. J. and W. (*op. cit.*, p. 265, pl 2, figs. 14–18); and *C. springeri*, St. J. and W. (*op. cit.*, p. 259, pl. 2, figs. 1–13), are each characterized by a more or less broad base, with a large central cone, and a series of smaller lateral cones on each side of it. The lateral cones, however, in each species are much longer than those of C. striatus, as well as being either angular or compressed

in section. The beautiful series of *C. wachsmuthi* approach nearer perhaps than either of the others, the base, as represented in *op. cit.*, fig. 3*b*, and the series of lateral denticles or cones approach very nearly to the specimen from Tynan, but in proportion to the width of the base the denticles are larger, whilst the central one is considerably shorter in proportion to its diameter.

Formation and locality: Mountain Limestone, Armagh, Tynan, in Ireland; also in Derbyshire, at Lowick, Northumberland, and Brigsteer near Kendal, in each case rare (M'Coy); Upper Wensleydale. Lower Limestone, Howrat, Dalry, West of Scotland (Young and Armstrong.)

Ex coll. Earl of Enniskillen.

Cladodus curvus, Davis.

(Pl. XLIX., fig. 14.)

Teeth, small or medium size, base not well exposed but apparently rather slender for the size and strength of the coronal superstructure. The latter is formed by three large cones, the central one is the largest, nearly half an inch in length and about equal to the breadth of the base, it has a double curvature, first bending forwards and nearer the apex curving round in a lateral direction to the left: the cone is strong, rotund, ·15 inch in diameter near the basal extremity, gradually contracting upwards and terminating in an acute point. The surface is deeply striated longitudinally, the ridges well defined with an acuminate edge separated by a wide sulcus. The ridges divide but without anastomosis. The lateral cones are unequal in size, the one forming the right extremity of the tooth being nearly equal in size to the central one, whilst the opposite one is smaller; the latter is straight half the length of the central cone, and extends at an angle of 45° from the base, it is striated similarly to the central one. The right lateral cone is only slightly smaller than the central one, it is straight and rises almost vertically from the base. It is separated from the central cone by a larger interspace, on which there may have been located a small denticle but which is not now present, than the opposite one. The crown is separated from the base by a transverse sulcus and ridge extending across the tooth.

The peculiar want of symmetry in the arrangement of the cones of this species renders it quite distinct from any other. It is placed in the genus provisionally because the base being hidden by the matrix it is impossible to form a safe opinion as to whether it possesses the broadly expanded base characteristic of the genus.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Cladodus destructor, Davis.

(Pl. XLIX., fig. 15.)

Teeth, of large size, 1·25 inches across the base and 1 inch in height, strong and robust. Base large and thick, elliptical in outline, ·6 inch wide, extending laterally

beyond the surface covered by the crown; base inclined with slight obliquity backwards. Crown divided into three large cones equal in size, and equidistant. Central cone, circular in section, slightly constricted at the base ·4 inch high, ·3 inch in diameter, conical, tapering, acuminate, upper portion of cone sigmoidally curved backwards. Surface finely striated, ridges coated with shining enamel are bifurcated repeatedly from the point to the base. Each lateral cone is about the same size as the central one and in all respects appear its counterpart. The structure of the coronal portion of the tooth is close, hard and dense, it is thickly coated with enamel: the basal part is a porous somewhat fibrous bony structure.

The peculiar and somewhat abnormal form of this unique specimen is sufficiently characteristic to distinguish it from any other species hitherto described. It possesses the broadly expanded base characteristic of the genus Cladodus. Its central and two lateral cones of nearly equal size differ very much from the ordinary form with comparatively large central cone, and lateral series of small ones, but there does not appear to be any sufficient generic distinction necessitating the institution of a new genus.

Its nearest ally is the species *Cladodus curvus,* previously described from the same formation at Armagh. The two are, however, quite distinct, the irregular and unsymmetrical arrangement of the cones in the latter render it easy to distinguish from this species.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Cladodus acutus, Agass.

(Pl. XLIX., fig. 17.)

Clododus acutus—	Agassiz, L.	1838.	"Poissons Fossiles," Vol. III., p. 199, pl. 22*b*, fig. 21.
,, ,,	Portlock, J. E.	1844.	"Geol. Report, Londonderry, &c.," p. 461.
,, ,,	Giebel, C. G.	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 323.
,, ,,	Pictet, F. J.	1854.	"Traité de Paléont.," Vol. II., p. 258.
,, ,,	M'Coy, F.	1855.	"Brit. Palæoz. Foss.," p. 620.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.

This species was described from a unique specimen by Prof. Agassiz, and, so far, the specimen remains the only one known.

"The principal cone is sharp and subulate, more conical than cylindrical, and slightly inclined backwards; its base is large and the point sharp. The secondary cones are of medium height, two on each side, striated similarly to the median one. The edge of the principal and lateral cones is produced so as to form a sharp-cutting surface. The base of the crown is hollowed out in the middle. Root short, and parallel with the base of the crown."—(*Agass*).

Prof. M'Coy considered that this species might have been young specimens of *Cladodus mirablis,* Ag., but after a careful examination of a large number of specimens of the latter, there appears to be a sufficiently well marked specific difference in the sharp

lateral cutting-edge of *C. acutus* to distinguish it from any other species. The median cone of *Cladodus striatus* is possessed of a sharp cutting-edge, but there can be no hesitation in distinguishing between the teeth of that species and the present one.

Formation and locality : Carboniferous Limestone, Loughgall, near Armagh.

Ex coll. Jones collection, Geological Society's Museum, London.

Cladodus milleri, Agass.

(Pl. XLIX., fig. 16.)

Cladodus milleri—Agassiz, L.		1838.	"Poiss. Foss.," Vol. III., p. 199, pl. 22*b*, figs. 22, 23.
Sphenonchus subulatus—Agassiz,			MS., in collections.
Cladodus milleri—Giebel, C. G.		1848.	"Fauna der Vorwelt," Vol. III., pt. 3, p. 323.
,, ,,	Pictet, F. J.	1854.	"Traité de Paléont.," Vol. II., p. 259.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt. p. 69.

Teeth. "The teeth have a great external resemblance to *Cladodus mirabilis:* the principal cone in particular approaches very near the same form, it is cylindrical, very slender and appears to have been obtuse at the summit. This cone is striated ; the striæ are much finer and more regular than *C. mirabilis:* the secondary cones are also more slender, either vertical or recurved backwards. Root is not well preserved. The base of the crown is undulated. The length of the tooth equals or exceeds the height of the principal cone."

An example of *C. milleri,* which is broken across the tooth, is represented in (Pl. XLIX , fig. 16). It is 1·4 inches in length, the principal cone is ·6 inch. There are three secondary cones on each side, the median one strongly implanted, rapidly tapering and acuminate. The principal cone in this specimen, terminates in a sharp point. This specimen differs somewhat from the description of Prof. Agassiz, the median cone is not so high or obtusely pointed, and the lateral cones are of more regular size and three instead of two in number.

Formation and locality : Mountain Limestone, Bristol.

Ex coll. British Museum.

Cladodus conicus, Agass.

Sphenonchus conicus—Agassiz, L.				MSS. in British Museum.
Cladodus	,,	Agassiz, L.	1838.	"Poiss. Foss.," Vol. III., p. 199, pl. 22*b*, fig. 24.
,,	,,	Giebel, C. G.	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 323.
,,	,,	Pictet F. J.	1854.	"Traité de Paléont.," Vol. II., p. 259.
,,	,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc." Vol. XVIII., p. 100.
,,	,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., of Glasgow," Vol. III., Supt., p. 69.

Prof. Agassiz distinguished this tooth from the Mountain Limestone of Bristol, under the name of *Sphenonchus conicus ;* finding it should be included in the genus

Cladodus he transferred it there. The example is stated to be unique. It is imperfect and a doubt is expressed as to whether it is a separate species. The principal cone is insensibly contracted towards the point, and in this it differs from *C. milleri*, Agass., with which it was found. The folds of enamel are not so fine and the base of the tooth is not so large. Secondary cones not present. I have not been able to find the type at the museum at Bristol, where Prof. Agassiz states it was located.

Formation and locality : Mountain Limestone, Bristol.

Cladodus basalis, Agassiz MSS.

(Pl. XLIX., fig. 18.)

Cladodus basalis,—Agassiz, L.,			Captain Jones's Collection MSS.
,, ,,	Portlock, J. E.,	1844.	"Geol. Report Londonderry, &c.," p. 461.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100

Teeth, comparatively small, base broad as central cone is long, breadth of base is ·4 inch. Median cone broad at the base, gradually tapering, curved backwards, anterior basal surface depressed and concave, surface above marked by a series of longitudinal ridges, broad and strong, separated by grooves about equal to them in width. Apex of cone much worn by attrition. Lateral secondary cones small, ·1 inch in length, two on each side, the external ones little if any larger than the intermediate ones ; striated in the same manner as the central cone.

The type specimen of this species was named by Professor Agassiz whilst in the collection of Admiral Jones, and was afterwards transferred to the Museum of the Geological Society. It presents somewhat similar features to *Cladodus mirabilis,* but more careful examination prove some points of difference. The tooth appears to be full grown judging from its worn appearance, and must consequently have belonged to a smaller fish than the great teeth of *C. mirabilis* The longitudinal ridges are much thicker and stronger than those of other species and do not present any of the thread-like appearance of the ridges on *C. mirabilis.*

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Geological Society's Museum.

Cladodus curtus, Davis.

(Pl. XLIX., fig. 19.)

Teeth, very broad strong base, median cone short, secondary cones small and numerous. Anterior surface of base only exposed ·9 of an inch broad, under surface flat, front rounded on each side with median depression. Crown, median cone ·3 of an inch in height, ·25 inch wide at the base ; higher it becomes rapidly smaller and ends in a sharp point, surface broadly striated. Secondary denticles

small, broadly and strongly implanted, converging to a finely pointed apex. Two extreme cones are the largest, they extend away from the centre.

This specimen appears to be unique.

Formation and locality: Mountain Limestone, Richmond.
Ex Reed Collection, Museum, York.

Cladodus hornei, Davis.

(Pl. XLIX., fig. 20.)

Tooth, medium size, 1·1 inch across the base, 1 inch in height. Base, subelliptical, thin, anterior face slightly rounded, depressed in centre, extending backwards at right angles to the median cone. Median cone long, tapering, with a slight double flexure, compressed from back to front; junction of anterior and posterior surfaces from a lateral cutting edge; surface covered with longitudinal ridges about their own diameter apart; near the apex it is smooth, apparently the result of wear, towards the base the ridges become more numerous and smaller, then disappear. Two lateral cones ·3 of an inch in length, round, divergent, pointed, striated similarly to median cone. Space between the median and lateral cones depressed and smooth.

This comparatively rare species stands apart from others of the same genus in its graceful attenuity and paucity of secondary denticles. It probably approaches near to *Cladodus striatus*, Ag., from the Armagh Limestone, to *C. elongatus*, Davis, from Richmond in Yorkshire, and to *C. elegans*, N. and W., from the St. Louis Limestone (Geol. Survey of Illinois, Vol. IV, p. 354, pl. iv., fig. 9). From the latter it is distinguished by the central cone being rounder, less compressed, and its attachment to the base less expansive and thinner. The general form of the tooth is similar to *C. elongatus*, but it is readily distinguished from that species by the presence in the latter of a large number of lateral cones. The same character also separates it from *C. striatus* as well as its more slender and feebler form.

I am indebted to Mr. William Horne, an enthusiastic naturalist, for the opportunity to describe this species, and as a tribute towards my indebtedness I venture to distinguish the species by appending his name.

Formation and locality: Carboniferous Limestone, Wensleydale.
Ex coll. William Horne, Esq.

Cladodus mucronatus, Davis.

(Pl. XLIX., fig. 21.)

Teeth, medium size, breadth of base ·8 of an inch, height of median cone ·5 of an inch. Base thick, median portion, beneath central cone, deeply hollowed, abruptly prominent on each side, retreating and terminating in an acute extension projecting some distance beyond each extreme lateral denticle. Crown composed of a central cone, with five lateral cones, two on one side, three on the other, the

outermost of which are largest; central cone widely implanted, rapidly tapering and terminating in an acutely pointed apex. Surface covered with longitudinal ridges, bold and prominent, about twenty in number near the base, diminishing to five or six near the apex. Secondary denticles, terminal ones largest, divergent, broad at the base, conical, slightly curved, pointed, striated as median cone; intermediate denticles small.

This species, with its sharp, regularly conical cusps and deeply sulcated base, is readily distinguished from *Cladodus mirabilis*, Ag., which is the only species which it nearly approaches.

Formation and locality: Carboniferous Limestone, Wensleydale.
Ex. coll. William Horne, Esq.

Genus.—Carcharopsis, Agass. MSS.

Carcharopsis—Agassiz, L., 1833. "Rech. sur les Poiss. Foss.," Vol. III., p. 313.

Teeth, length equal to twice greatest breadth; form triangular, broad at the base converging to a pointed apex, straight or slightly bent towards one side; transverse section elliptical or ovoid; antero-posterior diameter equal to half the lateral one; lateral margins deeply crenulated. Base somewhat constricted and less than the diameter of the basal portion of the crown, divided more or less into two branches with a deep intervening sulcus.

Prof. Agassiz in a foot note to the synoptical table of Squalides ("Poiss. Foss.," Vol. III., p. 313), makes the following brief reference to the teeth of *Carcharopsis prototypus*:—"I have designated under this name a very extraordinary type of tooth, obtained from the Carboniferous Limestone of England and Ireland, of which I shall give a description in the supplement of this work. In their general form, the teeth of this genus strikingly resemble those of the genus Carcharodon; they are equally compressed, triangular and denticulated along their edges, but the surface presents large folds towards the base of the crown. The genus appears to approach that of Petalodus of Owen, of which it may be necessary to form a separate family. The only example I have seen of *Carcharopsis prototypus* forms part of the collection of the Earl of Enniskillen."

From the above references to the resemblance of the new genus to those of Carcharodon and Petalodus there can be little doubt that the tooth which is here described as the type of the genus from the collection of the Earl of Enniskillen, and which has been so labelled during many years past, is the example which Prof. Agassiz intended to indicate. This being the case it necessarily follows that the determinations of some American palæontologists will require considerable revisions and modification.

Prof. M'Coy ("British Palæoz. Rocks and Fossils," p. 642, pl. 3 G, fig. 2, and pl. 3 K, fig. 11) describes two species of teeth which he considers form a genus possessing distinctive characters from others previously discovered. They are named

Pristicladodus and are described as consisting of a crown composed of one large, thick, compressed, sharply-pointed cone, with two denticulated cutting edges, the surface highly polished and either smooth or very finely striated; the base of the cone expands at right angles, forming a large semicircular, thick, coarsely osseous base from which there may be extended a single lateral cone on each or not. The teeth agree generally with those of Cladodus in the form of both base and crown, the latter, however, differs in the greater robustness of the principal cone, and especially in the denticulation of its edges. Prof. M'Coy remarks, "The first specimen which I saw of this genus I supposed might have been the *Carcharopsis prototypus* of Agassiz's lists, but subsequently finding a second which was still more nearly like Carcharodon, to which he likens his species, I hesitated to identify an undescribed fossil which I had never seen, more especially as neither of my specimens showed any trace of the ridges at the base of the crown alluded to by Agassiz; and the horizontally dilated base was so remarkable a character, totally separting them from Carcharodon, and nearly allying them to Cladodus, that I could not suppose that the true *Carcharopsis prototypus* was identical with my fossils, or the one resemblance would not have been stated and the other affinity overlooked." Two species are described, *P. dentatus*, triangular in outline, cone sharply pointed, base widely expanded and laterally tapering to a point without cones. This species is distinguished from the second one, *P. goughi*, by the strong, close, deeply-cut, regular dentation of its edges, and the deep triangular depression in the anterior face. The *P. goughi* is larger, it has a central and two lateral cones, one on each side.

In 1866, Newberry ("Geol. Surv. Illinois," Vol. II., p. 69, pl. VI., figs. 14, 14a) described a tooth from the Alabama Limestone very similar to the Pristicladodus of M'Coy. It is recognized as offering a near relationship to that genus, but though the name Pristicladodus is regarded as well chosen to indicate the relationship of the genus, he considered that it was anticipated by perhaps the equally appropriate one of Carcharopsis of Agassiz. The latter is therefore retained, the tooth being called *C. wortheni.*

In 1875, Messrs. St. John and Worthen ("Geol. Survey of Illinois", Vol. VI., p. 253) amended the genus Pristicladodus of M'Coy. The *P. dentatus* of that author is regarded as the type of the genus Carcharopsis of Agassiz and *P. goughi*, M'Coy retained as the type of the genus Pristicladodus. The genus Carcharopsis as thus amended is described, its principal features being the widely expanded central cone, sublenticular in transverse section, the lateral angles sharp and deeply and regularly crenulated: extremities occupied by one or two more or less slender, conical lateral denticles, which are as isolated as in the case of the typhical Cladodus. The amended genus Pristicladodus is characterized by the central cusp being strong, erect, sigmoidally recurved, rapidly converging to a point, "lateral edges sharp and more or less distinctly undulated or simple: lateral cusps relatively very strong, sometimes even more massive than the median cusps, divergent, similar in shape to the median

prominence, with which they are connected by a prominent sharp-curved intervening ridge ; anterior coronal surface marked with sharp more or less irregular costæ, which converge in the intermediate crest, producing a faint denticulation, sometimes forming quite strong spinous processes." The form described by Dr. Newberry under the name of *Carcharopsis wortheni*, is regarded as a typical representative of the genus first recognized by Prof. Agassiz, and intimately allied to, though probably specifically distinct from *Pristicladodus dentatus* of M'Coy, whether the latter is identical with the original form named by Agassiz *Carcharopsis prototypus* or not, the authors have not been able to ascertain, but "in assigning to each of those groups appellations which we believe to have been originally applied to quite different forms, in part at least, by Profs. Agassiz and M'Coy, we have been guided by such facts as are accessible to us, only desiring to render due justice to our own authorities."

After consideration of the several descriptions given above, it appears that the Carcharopsis of Agassiz was a tooth consisting of a crown formed of a single cusp or cone, deeply plicated or folded towards the base, the latter was much contracted in size compared with the diameter of the crown. M'Coy's genus Pristicladodus is also well defined, having a broadly expanded horizontal base resembling Cladodus, and in some instances a single lateral cone on each side the central one : the type species, *C. dentatus*, however, was not possessed of lateral cones. The specimens described by Newberry as *Carcharopsis wortheni* bear so close a resemblance to *Pristicladodus dentatus*, M'Coy, that there can be no doubt that it should be transferred to that genus. The genera Carcharopsis, Ag., and Pristicladodus, M'Coy, have one characteristic common to both, the central cusp is deeply serrate on each side, but in the *amended* descriptions given by St. John and Worthen ("Illinois." Vol. VI., p. 254), and indicated above, the lateral edges of the central cusps of the teeth included in the latter genus are "more or less distinctly undulated or simple," and the only species described, *P. springeri* is possessed of lateral cusps which are larger than the central one, and the edges of the central cusp are smooth. This divergence of characters warrant the doubts expressed by the authors as to the relationship of the specimens, and leads to the conclusion that they must be excluded from the genus Pristicladodus as defined by M'Coy.

Carcharopsis colei, Davis.

(Pl. XLIX., fig. 26.)

Tooth, length ·9 inch, breadth near the base ·45 inch, transversely elliptical or ovate in section, the lateral diameter being about twice that of the postero-anterior diameter. Broadest near the base, the tooth converges gradually to form an accuminate apex, curving slightly to one side, and has a generally triangular form ; anterior surface of the crown, transversely convex, longitudinally, along the median line, nearly straight, curving slightly towards the apex : at the basal extremity the

crown slightly converges and is divided into two branch-like roots with a median depression intervening. Laterally the crown is divided on each side into about a dozen deeply-cut crenulations: the latter strongly implanted, round, club-shaped, and curved towards the apex of the tooth: they are largest in the central portion of the tooth becoming smaller upwards, the point being without crenulations. The coronal surface is smooth and enamelled. The base short, convergent, divided into two branches which are less in diameter than the crown of the tooth.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Genus.—Pristicladodus, M'Coy.

Pristicladodus—M'Coy, F., 1854. "British Palæozoic Fossils," p. 642.

"Base of tooth expanded at right angles to the crown, large, sub-semicircular, thick, coarsely osseous; from the truncated straight edge of the base in front the crown rises as one large, thick, sharply-pointed, compressed cone, with two denticulated cutting edges, lateral cones very few (? one on each side or none), surface of crown highly polished and marked with fine longitudinal ridges, or smooth."—(*M'Coy*).

Pristicladodus dentatus, M'Coy.

(Pl. XLIX., fig. 22.)

Pristicladodus dentatus—	M'Coy, F.,	1854.	"Brit. Palæoz. Foss.," p. 642, pl. 3 G., fig. 2.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thes. Dev.-Carb.," p. 363.

Teeth, "medial cone large, triangular, rather flattened on the outer side, and with a deep triangular hollow, the base of which is parallel with, and a little above the base of the tooth, which is narrow, arched upwards in the middle, and not prominent; the sides of the hollow are parallel with the sides of the tooth; back of the crown rounded, sharply convex; cutting edges set with a row of strong, equal, sharply-defined, sub-cylindrical, obtusely pointed teeth, set at right angles to the edge (about three in the space of one line), about half their diameter apart, and rather longer than wide; base on inner side horizontally extended, thick, fibrous, almost semicircularly rounded; surface of large cone smooth on the outside, faintly striated longitudinally on the inner side."—(*M'Coy*). The specimen described by Prof. M'Coy was an imperfect one. The one now figured shows that the lateral extensions of the base from the central cone, were devoid of secondary denticles. It is 1·4 inches across the base, height of cone ·9 of an inch.

The specimen selected for illustration is from the collection of Wm. Horne, Esq., others occur in the Reed collection at the York Museum, and in Lord Enniskillen's

collection at Florence Court, (now at the British Museum, Cromwell-road), and also at the Natural History Museum, Newcastle-on-Tyne.

Formation and locality : Carboniferous Limestone, Wensleydale and Pateley Bridge in Yorkshire ; Black Up. Carb. Limestone, Derbyshire.—(*M'Coy.*)

Ex coll. Wm. Horne, Esq.

Pristicladodus concinnus, Davis.

(Pl. XLIX., fig. 23.)

Teeth, small, imperfect, breadth of base when complete ·4 of an inch, height of median cone equals the width of base. Base expanded, thin, slightly crushed, crown consists of one median cone, upper central portion accuminate, rounded, with lateral cutting edge ; lower portion expanded on each side to the same width as the base ; surface enamelled, smooth, cutting edges minutely and beautifully denticulated, a fold between each denticulation is continued along the surface of the tooth. Anterior face convex, no lateral or secondary cones.

This beautiful little tooth differs in details from *Pristicladodus dentatus,* it has nevertheless features in common with the genus, and it appears advisable to retain it in the genus, at any rate for the present.

Formation and locality : Carboniferous Limestone, Wensleydale.

Ex. coll. Wm. Horne, Esq.

Pristicladodus goughi, M'Coy.

(Pl. XLIX., fig. 27.)

Pristicladodus goughi—	M'Coy, F.,	1854.	"Brit. Palæoz. Fossils," p. 643, pl. 3 K., fig. 11.
" "	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101
" "	J. J. Bigsby,	1878.	"Thes. Dev.-Carb.," p. 363.

Teeth, "crown compressed, triangular, moderately convex, marked with close, sharp, irregular, longitudinal striæ, averaging five in one line, becoming obsolete at the apex, and close to the base of the crown ; cutting edges sharp, marked with broad, slightly-marked, tooth-like undulations, nearly their width apart, and generally blending at their base into the edge, being obsolete in the upper third of the cone ; lateral cones two, robust, sub-cylindrical, striated like the principal one. Height of principal cone, one inch two lines ; width of whole tooth, one inch three lines ; width at base eight lines ; height of side cone five lines ; width at base three and a half lines ; lateral breadth of base six lines ; lateral breadth or thickness of principal cone four lines."—(*M'Coy.*)

This example, from the Lower Carboniferous schists of Kettlewell and Kendal, located in the Woodwardian Museum at Cambridge, still remains unique. As already pointed out, it differs very materially from the type species, *P. dentatus.* It is a rounded, robust tooth, with strong secondary cusps, whilst *P. dentatus* is deeply compressed, and has no secondary cusps. The lateral denticulations of the median

cone are, compared with *P. dentatus,* very weak, had they not been present the tooth would have been a very exact representative of some species of Cladodus. It is retained in its present position with grave doubts as to its generic identity.

Formation and locality : Lower Carboniferous schists of Kettlewell and Kendal.
Ex. coll. Woodwardian Museum, Cambridge.

Genus.—Glyphanodus, Davis.

Teeth, consisting of a single pointed, conical, excessively thin, crown, cutting edge sharp, trenchant. Summit of crown inclined forwards. Surface ornamented by semi-radiating striæ. Base extending parallel with coronal surface, deep, coarsely osseous, thin, equal in breadth to that of the tooth.

Glyphanodus tenuis, Davis.

(Pl. XLIX., figs. 24, 25.)

Teeth, medium size, triangular, very thin. Crown consists of a single, conical, thin and laterally expanded surface, 1·0 inch wide at the base, and ·7 of an inch in height to the summit of the cone, gradually tapers to an accuminate apex. Anterior surface convex, corespondingly concave posteriorly. Marked by a large number of semi-longitudinal striæ : indistinct or absent towards the base. The striæ radiate to some extent from the centre of the tooth towards the lateral margins. The ridges are bold, separated by their own diameter from each other. Cutting edge sharp and smooth.

These teeth are peculiarly thin and slender. The base possesses more of the characters of the Petalodonts, extending downwards in a line with the surface of the crown rather than with the Cladodonts whose base extends backwards at right angles to the crown. The pointed surface of the crown, on the other hand, is more clearly related to the Cladodonts and especially with the modification found in Pristicladodus, from which however it is separated not only by the form of the root, but also by the absence of denticulations, on the lateral surface of the crown.

Formation and locality : Carboniferous Limestone, Upper Wensleydale.
Ex. coll. Wm. Horne, Esq., and Reed collection, Museum, York

Family.—Orodontidæ, L. G. de Koninck.

Ref. " Fauna du Calcaire Carb. de la Belgique," p. 29, 1878.

Prof. Agassiz, in the " Recherches sur les Poissons Fossiles," pointed out and insisted on the intimate relationship existing between the still surviving Cestracions of the Australian and Chinese seas and the fossil genus Orodus of the Carboniferous series. M. de Koninck (" Fauna du Calcaire Carbonifére de la Belgique ") united

under the term Orodontidæ, the genera Orodus, Agassiz; Lophodus, Rowanowsky; and Petrodus, M'Coy: "parce que les dents des deux premiers de ces genres ont une forme générale qui les rapproche les unes des autres, et que celles du troisième ont une très grande analogie par leur structure interne et par leur forme extérieure avec les dents antérieures des Cestracion." The Orodontidæ is regarded by M. de Koninck as a group of the family Cestraciontidæ, but no further definition is given

The teeth of the genera comprised in the Orodontidæ, which have been found in the Carboniferous rocks of the British Islands, are in nearly all cases quite dissociated and separated into single specimens. In a few rare instances, as in Pl. L., figures 1 and 3, two or three teeth are found united antero-posteriorly, but in no instance have teeth been discovered whose lateral extremities have been either united or placed in such a relative position as to exhibit the method of arrangement transversely; neither have they served in any way to indicate how the teeth were disposed on the jaws, or the number which existed in each fish. It is probable that the circumstances attending their deposition may account for the separation of the teeth. The limestone, in which the specimens are found, would naturally be a deposit which accumulated slowly, so that the body of the fish, with the exception of the teeth and the spines, if they had any, being composed entirely of cartilage and fleshy substances, easily decayed. As the connecting tissues became decomposed, the teeth, released from their attachment, were disturbed and more or less distantly separated by the action of waves or currents, and it was only in rare instances that two or three teeth became embedded in the sediment with sufficient rapidity to secure their preservation in natural juxtaposition. It is fortunate that other specimens have been found in shales of the Coal Measures of Osage County, Kansas, in America, which are well preserved, and retain the same or nearly the same relative position to each other in the fossil state which they bore when living. The deposition of the mud forming the shales doubtless proceeded with much greater rapidity and less disturbance than that of the limestones, and the result has been that the fishes became buried in the sediment before a sufficient time had elapsed for their decomposition and dispersion, and the hard parts are preserved in a more or less natural and undisturbed state.

A consideration of the Kansas specimens throws much light on the nature and relationship of the Orodontidæ as a group. They are described by Messrs. St. John and Worthen, in the "Palæontology of Illinois," Vol. VI., p. 311, and are considered by the authors as a separate genus, for which they have instituted the name Agassizodus, in acknowledgment and recognition of the services of that eminent ichthyologist. The specimen (*op. cit.*, pl. VIII., figs. 1–22) consists of about four hundred and fifty to five hundred teeth in their natural position, and comprises the whole of the left ramus of what appears to be the mandible or lower jaw and a few teeth of the right mandible. After describing the arrangement of the teeth, the authors remark that the teeth present "almost precisely the same

appearance the spread out diagram of the dental armature of Cestracion would present, as obtained by stripping off the teeth and spreading them upon a flat surface. Hence in attempting the restoration ("Palæont. Illinois," Vol. VI., p. 312, pl. viii., fig. 22), it is obvious that sufficient allowance may not have been made for the inrollment of the anterior portion of the jaw, thus producing an outline more obtusely angular in front than may have obtained in reality. Yet, compared with the modern Cestracion, the jaws of the remarkable fish under consideration were doubtless less acutely produced forward, and, in this particular, holding a mean between its modern representative and some of the Rays (*e.g.* Trygon) in the relative obtuseness of the anterior extremity of the jaws. But the resemblance here ceases. In all other respects, as the form of the individual teeth and their arrangement upon the jaws, we observe unmistakable Hybodont affinities." The teeth are disposed in serial rows having a convoluted inrollment from the inner to the outer border, and gradually increasing in size from the posterior extremity to the row of large median teeth, anterior to which the rows are regularly diminished in size towards the symphysis. In addition to the teeth, masses of cartilage are preserved and certain peculiar little bodies of irregular form, but generally more or less circular and delicately sculptured with irregular carinæ radiating from the apex towards the marginal borders, concave below. These are considered to have constituted the dermal or shagreen covering of the fish. No spines have been found.

The teeth of Agassizodus present the closest affinities to those of the genus Orodus, Agass., they are distinguished by the prevailing prominence of the buttressed condition of the anterior coronal borders and the relative uniformity or evenness of the posterior face, besides the relatively fewer rows of accuminate teeth, as inferred from this feature being so prevalent in all collections of Orodi, while the linear forms are least commonly met with. The genus appears to be confined to the Upper Carboniferous or Coal Measure period, and it is not at all improbable that this genus constitutes the representative of Orodus in these horizons, since only a single form of the latter genus has been noticed from the Coal Measures and that may prove to belong to the genus Agassizodus.

For comparison with the fossil forms, it may be well to cite the description of the dentition of Cestracion given by Prof. Owen ("Odontography," p. 51). He says: "The teeth at the anterior part of the jaws are smallest; they present a transverse, sub-compressed, conical figure, with the apex produced into a sharp point; these points are worn away from the used teeth at the anterior and outer parts of the jaw; but are strongly marked in those which still lie below the margin. There are six subvertical rows of these small cuspidate teeth on each side of the jaw, together with a median row close to the symphyseal line; and from twelve to fourteen teeth in a row. Behind the cuspidate teeth, the five consecutive rows of teeth progressively increase in all their dimensions, but principally in their antero-

posterior extent; the sharp point is converted into a longitudinal ridge, traversing a convex crushing surface; and the ridge itself disappears in the largest teeth, as the teeth increase in size they diminish in number in each row; the series of the largest teeth includes from six to seven in the upper, and from seven to eight in the lower jaw. Behind this row, the teeth, although preserving their form as crushing instruments, progressively diminish in size; while at the same time the number composing each row decreases. From the oblique and apparently spiral disposition of the rows of teeth, their symmetrical arrangement on the opposite sides of the jaw, and their graduated diversity of form, they constitute the most elegant tesselated covering of the jaws which is to be met with in the whole class of the fishes."

Comparing the above description of the still existent Cestracion and the Coal Measures Agassizodus, a striking simlarity is observed in general form and arrangement of the teeth on the jaws, as well as in the characteristics peculiar to the teeth individually. It is only in matters of detail, in the number of the teeth in each row, and the number of rows, that any striking difference is perceptible. The dentition of Cestracion is adapted to crush hard and resistent objects like the shells of the mulluscs, or the hard covering of crustaceans, and it is probable that the teeth of the Orodonts were used for the same purpose.

Neither in American nor English strata have specimens been discovered which illustrate more than the arrangement of the teeth. Whether the fishes possessing them were possessed of defensive spines as in the case of the modern representative, is unknown.

A comparison of the recent and fossil teeth will afford some idea of the great size of the Cestraciont fishes of the Carboniferous age. The living fish found in the Australian seas is two to three feet in length, and the jaws occupy about one-eight of that length. The jaw of one of the larger specimens of Orodus ramosus must have been at least three feet in length—if we may deduce the length of the jaw from the relative size of the teeth—and the jaws being one-eighth the length of the entire body, gives the latter at twenty-four feet.

The following British genera appear to possess characters which associate them in one group and they are, along with the American genus Agassizodus, here included in that of Orodontidæ :—

Orodus, Agassiz.
Lophodus, Rowanowsky.
Petrodus, M'Coy.
Agassizodus, St. John and Worthen.
Rhamphodus, Davis.
Diclitodus, Davis

Genus.—Orodus, Agassiz.

Orodus—L. Agassiz, 1836. "Poissons Foss.," Vol. III., p. 96.

"Teeth, laterally elongated, having their middle portion more elevated than their extremities, forming in the central portion of the tooth an obtuse and transverse cone : the longitudinal transverse diameter, which much exceeds the transverse (here called antero-posterior), is also marked by a ridge sometimes medial, sometimes submedial, from which spring oblique secondary ridges which ramify upon the sides, and which in the larger teeth, give rise to another series of collateral ridges."

The teeth of the fishes of this genus vary greatly in form and; size they may be longer or shorter, straight or strongly arched, strong and thick or slender and attenuated, with large conspicuous roots or small ones, and in some instances apparently rootless, and all from the same fish, differing according to their position in its mouth. They appear, nevertheless, to have tolerable persistent similarity in the surface decoration of the crown, and this character serves better than any other to distinguish the several species.

The genus Orodus is entirely restricted to the Carboniferous rocks, so far as is known. In the British Islands it is found in the Mountain Limestone and Yoredale rocks, and may have ascended to the Coal Measures, specimens having been found in the shales of the Lancashire coalfield which are attributed to this genus.

Orodus timidus, H. Trautschold, does not belong to this genus (L. G. de Koninck).

Orodus ramosus, Agass.

(Pl. L., figs. 1–7.)

Orodus ramosus—	L. Agassiz,	1836.	"Recher. sur les Poiss. Foss.," Vol. III., p. 97, pl. xi., figs. 5, 6, 7 and 8.
,, ,,	Sir P. Egerton,	1837.	"Catalogue of Fossil Fishes."
,, ,,	J. E. Portlock,	1843.	"Rep. Geol. of Londonderry, &c.," p. 467., pl. xiv. *a*, fig. 8.
,, ,,	L. G. de Koninck,	1844.	"Disc. der Anim. foss. du terre Carbonif., de la Belg." p. 613, pl. lv., fig. 2.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 342.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 852.
,, ,,	F. Roemer,	1851.	"H. G. Bronn's "Lethæa.," Vol. I., p. 709, pl. ix., fig. 9.
,, ,,	F. A. Quenstedt,	1852.	"Handb. der Petrefact.," p. 188.
,, ,,	F. J. Pictet,	1854.	"Traité de Palæont.," Vol. II., p. 264.
,, ,,	J. Morris,	1854.	"Cat. of Brit. Foss.," p. 335.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	H. Rowanowsky,	1864.	"Bul. de la Soc. Imp. des Natur. de Moscou," p. 158, pl. iii., fig. 2
,, ,,	Enniskillen,	1869.	"Alphab. Cat. of Type Spec. of Foss. Fish.," p. 6.
,, ,,	H. Trautschold,	1874.	"Die Kalkbrücke von Miatchkowa," p. 16.
,, ,,	W. H. Bailey,	1875.	"Fig. Charact. Brit. Foss.," p. 120, pl. xli., fig. 10.
,, ,,	F. Roemer,	1876.	"Lethæa palæozoica," pl. xlviii., fig. 8.
,, ,,	L. G. de Koninck,	1878.	"Fauna du Calc. Carbonif. de la Belgique," p. 30, pl. iv., fig. 1.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 359.

Teeth, large, powerful, massive: transverse diameter about three times that of the antero-posterior one: median surface of crown broad, narrowing laterally to two-thirds its diameter; lateral terminations bluntly subtruncated. Median cone prominent, with an acutely-angular antero-posterior ridge, on each side a median carina somewhat sinuously descends to the lateral extremities, with divaricating anterior and posterior ridges, the latter occasionally bifurcating into two or more branches as they approach the margins. The carina and ridges in unworn specimens are sharp and well defined, separated by deep and wide concave furrows. Surface uniformly punctate. Base of crown irregularly concave. Root, very large, about four times the depth of the crown, coarsely fibrous or spongy, full of lacunal interstices. Anterior surface slightly convex, deeper than posterior which is concave: base joins the two diagonally having nearly the same antero-posterior diameter as the crown. Dimensions of a large example, transverse diameter four inches, antero-posterior diameter 1·2 inches; thickness of crown ·2 to ·4 of an inch; depth of base 1·1 inches.

The teeth of *Orodus ramosus* exhibit considerable variety in form as well as surface ornamentation. In one of the largest examples Pl. L., fig. 2, the number of bifurcating branches from the median lateral carina is very large and intricate. In the same specimen the surface of the crown is so close in texture that only a very slight trace of the punctuation is visible, though in other specimens of equal size it is very easily perceptible. The series of three large teeth represented in Pl. L., fig. 1, from the Bristol Museum, appear to be much worn, both the median cone and the lateral carina and ridges are almost obliterated. The specimen Pl. L., fig. 1, as well as the one represented by Pl. L., fig. 3, from the collection of Lord Enniskillen, are interesting because they exhibit the relative position occupied by the teeth in the mouth, the central cones in each case being contiguous, whilst the lateral extensions are separated.

Professor Agassiz expresses a doubt as to whether the teeth of *O. ramosus*, and *O. cinctus*, may not have belonged to one species. Professor L. G. de Koninck appears also to consider that the two should be united (" Fauna du Calc. Carbonif. de la Belgique"). After a very careful examination of all the material available, however, it appears probable that the determinations made by Professor Agassiz in the first instance are correct. The small specimens of *O. ramosus* are as distinctly ridged as the larger ones (see Pl. L., figs. 6, 7), and throughout appear to possess the same characters, whilst the smooth rounded forms of *O. cinctus* are equally persistent.

The teeth of *Orodus ramosus*, Agass., have been most commonly found at Bristol in the black limestone. Specimens have also been obtained at Oreton, in Shropshire, and a single specimen from Armagh exists in the collection given by the late Admiral Jones to the Geological Society. The latter presents some features differing from the Bristol specimens. Its transverse diameter is greater in proportion to the antero-posterior one, and it is laterally much more attenuated. The

crown of the tooth is sub-triangular, the ridge being quite as far removed from the base as the tooth is broad, whilst in the Bristol specimens, the teeth are broad and much depressed. The teeth of *O. ramosus* from Oreton are beautifully preserved, the surface decoration being particularly distinct and clear. The primary divaricating ridges are much fewer than in either the Bristol or Armagh forms, they are irregularly branched, and, especially on the median cone, are somewhat complex. The crown is slightly raised in the centre, due simply to the greater thickness of the median cone, the base of the crown is approximately straight, and from the summit of the median cone the lateral extensions gradually thin out, at the same time the antero-posterior diameter becomes contracted and the termination is, compared with the others, very acute.

The great fishes of this species which occupied the area around Bristol appear to have had congeners in other localities, of smaller size and, so far as the teeth are concerned, somewhat modified form; they do not present, however, sufficiently divergent characteristics to warrant the supposition that they were not the same species.

Formation and locality : Mountain Limestone, Bristol ; Oreton ; Armagh.

Ex coll. Earl of Enniskillen ; Bristol Museum ; Museum of the Geological Society, London.

Orodus cinctus, Agass.

(Pl. L., figs. 8, 9.)

Orodus cinctus—	L. Agassiz,	1838.	"Rech. s. les Poiss. Foss.," Vol. III., p. 96, pl. xi., figs. 1–4.
„ „	J. E. Portlock,	1843.	"Geol. Report, Londonderry, &c.," p. 467.
„ „	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 342.
„ „	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 852.
„ „	F. J. Pictet,	1854.	"Traité de Paléont," Vol. II., p. 264.
„ „	J. Morris,	1854.	"Catal. of Brit. Foss.," p. 335.
„ „	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„ „	Young & Armstrong,	1871.	"Trans. Geol. Soc. of Glasgow," Vol. III., supt., p. 73.
„ „	L. G. de Koninck,	1878.	"Fauna du Calc. Carbonif. de la Belgique," p. 31, pl. iv., fig. 2.
„ „	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, medium size, rounded and smooth, transverse diameter equal to four times or more that of the antero-posterior one. Median surface of crown largely developed, forming a rotund, smooth, somewhat detached cone, with a more or less deep sulcus extending across the tooth antero-posteriorly. Lateral prolongations of the coronal surface taper gradually towards each extremity which is usually obtusely rounded. There is no central carina as in *O. ramosus.* Three or four rather deep sulci extend across the tooth from front to back, on each side of the median cone, surface uniformly punctate. Root, large, laterally co-extensive with the crown, about double the depth of the central cone ; structure, porous, vesicular.

Length of tooth 1·4 inches in lateral diameter, antero-postero diameter ·35 inch, thickness including base ·6 of an inch.

This tooth is distinguished from that of *Orodus ramosus* by the absence of the lateral median carina and in the general simplicity of its coronal surface.

An example from the Bristol Museum (Pl. L., fig. 8.) shows the position of four teeth in natural sequence. The inner ones are almost straight, the lateral extremity broadly expanded, whilst those placed externally are concavo-convex, narrow and laterally somewhat more pointed.

This species is found in the bone-bed at the base of the Mountain Limestone at Bristol, whilst *O. ramosus* is found only in the black limestone above.

Formation and locality: Mountain Limestone bone-bed, Bristol.
Ex coll. Earl of Enniskillen; Bristol Museum.

Orodus porosus, M'Coy.

(Pl L., fig. 10.)

Orodus porosus—	M'Coy,	1848.	"Ann. and Mag. Nat. Hist." 2nd Ser., Vol. II., p. 131.
" "	F. J. Pictet,	1854.	"Traité de Paléont," Vol. II., p. 264.
" "	J. Morris,	1854.	"Brit. Foss.," p. 335.
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, "sub-cylindrical, transverse diameter (or length of base) six or seven times greater than the antero-posterior; anterior and posterior margins nearly parallel, the middle being scarcely wider than the ends, which are obtusely subtruncate; sides slightly tumid, converging to a narrow mesial ridge; one small obtuse mesial cone not exceeding the short diameter of the base in height, and forming an obtuse ridge to the base on each; on each side there are four or five smaller tubercles, the smallest towards the ends, only those nearest the centre send one or two small ridges down the anterior side, while the posterior is more regularly ridged: basal margin tuberculato-plicate; surface coarsely punctured, except on the prominent worn points which are smooth; transverse diameter usually about nine lines, short diameter one and a half line."—(*M'Coy.*)

This species was described by Prof. F. M'Coy in the "Annals and Magazine of Natural History," without illustration, as was also *Orodus compressus*, M'Coy. Both form a part of the collection of types presented to the Geological Society by the late Admiral Jones.

Orodus porosus, M'Coy, most nearly approaches *O. elongatus*, Ag., in general character. It may be distinguished from it, by the lateral ridges being produced along the upper surface of the crown, with the carina, so as to form a number of small secondary cones. The crown is also level and straight, whilst in *O. elongatus* it is raised in the central portion to form a wide median cone.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Museum of Geological Society.

Orodus compressus, M'Coy.

(Pl. L., fig. 11.)

Orodus compressus—	M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd Ser., Vol. II., p. 131.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 264.
,, ,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 335.
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, "much compressed, crown elevated into a thin edge of equal height throughout, surmounted by a fine ridge, and festooned by four or five sharp points on each side; the centre has a large point, producing a globular swelling in the middle of each of the flattened sides, over which it sends a small flexuous ridge, giving out short branches on each side, while the lateral points only send short simple ridges not half way down the sides; ends abruptly truncated; base surrounded by a sharply defined thickened border; surface smooth; highly polished; root nearly as deep as the crown is high; truncated below and at the ends; height of crown one line, width of base three and a half lines."—(*M'Coy.*)

This species is one of the smallest found in Britain. The thin compressed edge of the crown is a character possessed by *Orodus carinatus,* St. J. and W. ("Palæont. Illinois," Vol. VI., p. 307, pl. v., fig. 24.) but the detailed surface markings are quite distinct from that species.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Museum, Geological Society, Burlington House.

Orodus elongatus, Agass. (MSS.)

(Pl. LI., figs. 1, 2, 3.)

Teeth, medium size, extremely long in proportion to the width; transverse diameter 1·75 inches, antero-posterior diameter ·25 of an inch in the centre, barely more than ·1 of an inch on each side, lateral terminations rounded. Central prominence moderately elevated, with a ridge extending across from the anterior to the posterior margins, lateral prolongations unequal, one more depressed than the other, branching at right angles from the ridge across the central cone, two lateral ridges descend to the right and left extremities respectively, from the lateral carina numerous secondary ridges branch out on either side, of these the smaller disappear, or two frequently converge, forming a Y-shaped fold, the lower portion of which becomes attenuated or disappears before reaching the basal margin; the latter smooth and slightly sulcated. Root large, transversely a little wider than the crown, central part and shorter extremity twice the depth of the crown, towards the longer and more depressed extremity the root is proportionately smaller, base of root smooth and straight, except a slight median concavity. Structure porous and open.

This species differs from *Orodus angustus,* Ag., in the possession of a median carina and in the prominence of the central cone. It is also longer and more

attenuated in proportion to its length, the secondary lateral ridges are more regular and symmetrical in arrangement.

Formation and locality : Mountain Limestone, Armagh.
Ex. coll. Museum of Geological Society, London ; Earl of Enniskillen.

Orodus angustus, Agass. (MSS.)

(Pl. LI., fig. 4.)

Orodus angustus—	L. Agassiz,		"MSS., Capt. Jones' Collection Geol. Soc., London."	
"	"	J. E. Portlock,	1843.	"Report Geol. Londonderry, &c.," p. 461.
"	"	J. Morris,	1854.	"Cat. Brit. Foss.," p. 335.
"	"	Morris and Roberts	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
"	"	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, medium size, uniformly narrow, transverse diameter 1·1 inch, width of central cone ·15 of an inch, laterally slightly less; lateral terminations rounded, median elevation slight with an antero-posterior ridge, no lateral carina, numerous ridges parallel with the median one, antero-posterior section circular, base of crown contracted, surface uniformly punctate. Root slightly deeper than the height of the crown, concavo-convex, base concave, corresponding to the convexity of the crown, coarsely porous in structure.

This species, along with *O. elongatus, O. gibbus,* and *O. catenatus,* were named in Manuscript, by the late Prof. Agassiz from three specimens in the collection of the late Admiral Jones. The types so named were presented to the Geological Society, London, by Admiral Jones, and form the subjects of the present descriptions, along with others selected from the collection of Lord Enniskillen.

The teeth of *Orodus angustus,* Ag., may be distinguished from those of *O. elongatus,* Ag., by the absence of a lateral keel or carina, the more uniform diameter of the tooth antero-posteriorly, the almost entire absence of a central cone and the irregular arrangement of the ridges on each side. Similar characters also separate it from *O. porosus,* M'Coy.

Formation and locality : Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen ; Museum, Geological Society.

Orodus catenatus, Agass. (MSS.)

(Pl. LI., figs. 5, 5*a.*)

Orodus catenatus—	L. Agassiz,		"MSS., Capt. Jones' Collection, Geol. Soc., London."	
"	"	Portlock,	1843.	"Report Geol., Londonderry, &c.," p. 461.
"	"	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
"	"	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, small, ·35 of an inch in transverse diameter. Crown rises from each lateral extremity with uniform gradation to the median cone. The latter is prominent, round ; apex smooth, probably from wear. Median ridge extends from central cone along each lateral extension. From the median ridge secondary ones

branch out anteriorly and posteriorly, each speedily bifurcating and afterwards encircling the base of the crown after the manner of a chain. Root deeper than the height of the crown ; anteriorly prominently convex ; posteriorly concave ; usual porous structure.

This species appears to be sufficiently distinguished by its surface ornament and small size. There is always the possibility that small specimens may be the teeth of young fishes of other species, but in this instance such a probability is remote. The teeth were named by Prof. Agassiz but not described or figured.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen ; and Museum, Geological Society.

Orodus gibbus, Agass. (MSS.)

(Pl. LI., figs. 6, 7.)

Orodus gibbus—L. Agassiz "MSS., Capt. Jones' Collection, Geol., Soc., London."

,,	,,	Portlock,	1843.	"Report Geol., Londonderry, &c.," p. 461.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 335.
,,	,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth, medium size, peculiar humpy form ; transverse diameter 1·1 inch ; antero-posterior diameter of central cone ·35 of an inch ; lateral portions about half the diameter of the central cone, with one or more secondary cones on each side ; lateral terminations obtusely rounded ; base of crown much contracted antero-posteriorly ; central cone large, gibbous, expanded prominently before and behind, overhanging the base. The coronal surface contracts abruptly on each side for a distance equalling the diameter of the median cone, when it becomes again expanded to form secondary cones ; occasionally there are two secondary cones on one or both lateral extensions ; surface smooth, uniformly punctate ; base of the crown slightly crenulated. Root equal in depth to the height of the crown and co-extensive laterally ; coarse spongy texture ; anteriorly convex ; posteriorly deeply concave ; under-surface smooth.

The species, by its gibbous form, is readily distinguished. There are a number of specimens in the collection of Lord Enniskillen which appear to belong to this species, they are not so regular in form as the types, and are much worn apparently by attrition, the cones being reduced almost to the level of the remaining portion of the tooth. One specimen affords evidence of having possessed a row of small tubercles along the anterior basal margin of the crown.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen, Museum of Geological Society.

Orodus sculptus, Davis

(Pl. LI., figs. 8, 8*a*.)

Teeth, medium size ; transverse diameter 1·3 inches ; from anterior to posterior

margins ·3 inch ; raised portion of crown occupies a position nearer one end than the other. Not marked by any different feature to the remainder of the surface except that it is a little broader. An acutely raised ridge extends across the cone and along the lateral extensions to the extremities. From this a large number of minor ridges branch out at right angles. The latter frequently become broken into tubercles which extend over the surface mostly near the base. Root not exposed.

This example is placed in the genus Orodus with some doubt; it appears to possess many characters in common with other recognized members of the genus, but in some respects it diverges considerably. The median cone is less developed than in any other species and the tuberculated ridges are peculiar. It appears, however, to approach Orodus nearer than Helodus or Lophodus.

Formation and locality : Mountain Limestone, Bristol.
Ex coll. Bristol Museum.

Orodus ornatus, Davis.

(Pl. LI., figs. 9, 9*a*.)

Teeth, small, transverse diameter ·5 of an inch ; antero-posterior diameter ·2 of an inch ; crown consists of median cone with two or more lateral secondary cones on each side. Median cone large, prominent, apex smooth, with a radiating series of minute ridges or foldings of the enamelled surface, gradually absorbed in the smooth surface lower down ; a carina extends across the cone and is continued laterally to the end of the tooth, it is tuberculated along its entire length. The anterior and posterior basal margins of the crown are formed by a series of folds in the enamel which are continued on the secondary cones. On each side of the central cone is a deep depression from which the wall of the secondary cone rises at a sharp angle, from its apex it slopes gradually to rise again abruptly to form the next cone. An antero-posterior ridge runs across the cones, which is also, in most cases, tuberculated similarly to the median carina. Root not exposed.

This species approaches most nearly to *O. moniliformis*. It differs from it in the greater thickness and breadth of the crown, the presence of tuberculate projections along the lateral carina and the central cone, and in the form of the secondary cones, which are not so round as in *O. moniliformis*, but present more the form of an inverted cone.

The surface of crown of the tooth now described when magnified presents an extremely ornate appearance which has suggested the *nomen triviale* applied to the species.

Formation and locality : Mountain Limestone, Richmond, Yorkshire.
Ex coll. Earl of Enniskillen.

Orodus moniliformis, Davis.

(Pl. LI., figs. 10, 11, 12.)

Teeth, medium or small, transverse diameter one inch, central cone largest, more or less circular, separated by a deep sulcus from the secondary cones, of which there are four to six on each side, diminishing in size towards each lateral extremity of the tooth. Surface in small specimens smooth; in larger ones, the apex of each cone is minutely striated; lower part corrugated from the base of the crown upwards but disappearing before reaching the apex. Between each corrugation there are a number of small transverse plications, near and parallel to the base, which are continuous from the central round the lateral cones. Root short, not so wide as the crown, coarse in structure, containing numerous lacunæ.

This species is characterized by its somewhat flattened crown and short root, and more especially by the semi-detached appearance of the cones forming the crown.

It bears a superficial likeness to *Orodus mammillaris*, N. and W. ("Palæont. of Illinois," Vol. II., p. 66, pl. iv., figs. 10, 10*a*); the cones in the latter have a greater vertical altitude, the ridges are more prominent and frequently beaded, of which there is no trace in the Orodus now described. The root of *O. mammillaris* is also shorter than in this one.

From *Orodus ornatus*, Dav., of the Richmond limestone, it is readily distinguished by the absence of small tubercles along the lateral carina and central cone, which to some extent are characteristic of that species.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Orodus reedi, Davis.

(Pl. LI., figs. 13, 13a.)

Teeth, small, probably ·7 to ·8 of an inch in transverse diameter; height of crown ·2 of an inch, antero-posterior diameter about equal to the height of the crown, median cone prominent, anteriorly and posteriorly dilated forming a bold ridge from which minor ones branch right and left, reaching to the base, laterally compressed: a carina extends from the median cone, on each side, at right angles to the median one named; bold ridges, separated by deeply channelled grooves, branch out from the central carina and descend to the base of the crown. At least one secondary cone occurs on each side the median one and its ornamentation is similar to the median one. Surface uniformly and coarsely punctate. Root, concavo-convex, structure open and porous.

The peculiar arrangement of the ornamentation of this tooth (as shown on Pl. LI., fig. 13a) separates it from any other species hitherto described. It is very elegant and though the extremities of the tooth are broken off, the part existing is well preserved.

The specimen is unique from the thick bedded Mountain Limestone of Settle, in Yorkshire. It is comprised in the magnificent collection of fossils from the Yorkshire limestone collected by the late Mr. Wood, of Richmond, and since purchased by Dr. Reed, of York, and presented to the museum of that city. In recognition of the generous donor and his kind assistance to myself, I venture to attach his name to this species.

Formation and locality: Mountain Limestone, Settle, Yorkshire.
Ex. Reed Collection, York Museum.

Orodus tenuis, Davis.

(Pl. LI., fig. 14.)

Teeth, transverse diameter very long in comparison to that of the antero-posterior; crown, with a prominent median cone placed slightly towards one side, sub-rotund; lateral extremities depressed, expanded anteriorly and posteriorly to the basal margins; anterior basal margin prominent with slight tuberculations. A median ridge extends from the central cone to the ends, terminating sub-acutely. Surface smooth, coarsely punctate. Base, equal to crown in transverse diameter; depth equal to height of median cone, retreating from front, posteriorly-concave.

This species approaches nearly to *Orodus elongatus* but differs from it in the absence of antero-posterior lateral ridges and the depressed form of the lateral extensions of the crown.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Orodus subteres, Agass. (sp.)

(Pl. LI., figs. 15, 15*a*.)

Psammodus	subteres	—L. Agassiz,	1833.	"Poiss. Foss.," Vol. III., pl. xii., figs. 3–4.
Helodus	,,	,,	1838.	,, ,, ,, ,, p.105, pl. xii., figs. 3–4.
,,	,,	E. G. Giebel,	1848.	"Fauna der Vorwelt.," Vol. I., pt. 3, p. 340.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 583.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 647.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 328.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267.
,,	,,	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 357.

Teeth, "straight, very long, elevated medially forming an obtusely rounded cone. The lateral portions are circular without ridges, uniformly covered with minute pores. The margin of the longest end projects slightly, it is uniformly punctate with the remaining surface."—(*Agassiz.*)

Professor Agassiz observes that this tooth, which still remains unique, might be taken for a gigantic example of *Helodus lævissimus*, Agass., except that it lacks the highly polished surface of the latter.

This example, originally figured by Professor Agassiz as *Psammodus subteres,* and afterwards described as *Helodus subteres,* appears in some important characteristics to approach nearer to the teeth of Orodus than to those of Helodus. One of the most important distinctions between the two genera consists in the form of the base of the crown and its attachment to the root. In Helodus, the base of the crown spreads out from the central cone, more or less in every direction, but especially towards the anterior and posterior margins, forming in many instances quite a concave flexure from the apex to the basal margins. The apex of the crown is generally more or less acutely pointed or knife-like. The root of Helodus was attached to the palate in a superficial manner as compared with that of Orodus, and consists of a thin, deeply concave, often short, bony substance. On the other hand, the crown of Orodus descends from the median cone and lateral surfaces with a convex flexure, and the basal margins are incurved and rounded : the apex of the cone is rounded, generally more or less bulbous, and the root is long, comparatively thick and openly porous.

The specimen described by Agassiz as *Helodus subteres* has a median cone which is obtusely rounded, the lateral prolongations, though not possessing the median ridge which the Orodi generally do, is rounded and the basal margins are incurved. There is also a portion of the root preserved which is decidedly Orodont in appearance. It is thought advisable, notwithstanding the smoothness of the surface to recognize the characters indicated and to transfer the specimen to the genus Orodus.

Formation and locality : Mountain Limestone, Black Rock, Bristol.
Ex coll. Bristol Museum.

Genus—Petrodus, M'Coy.

Petrodus—M'Coy, F., 1854. "Brit. Palæoz. Foss.," p. 637.

"Teeth, conical, supported on a nearly circular osseous base, concave beneath; crown with a dense compact surface, height not exceeding the width, deeply furrowed with rough radiating ridges."—(*M'Coy.*)

Petrodus patelliformis, M'Coy.

(Pl. LI., figs. 16, 16*a*, 16*b*.)

Petrodus patelliformis—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," Second series, Vol. II., p. 132.
,, ,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 337.
,, ,,	,,	1855.	"Brit. Palæoz. Foss.," p. 637, pl. 3G., figs. 6, 7, 8.

Teeth, "conical, height one-half to two-thirds the width of the base, which is round or rarely subtrigonal ; apex rudely pointed, becoming flat by wear ; sides radiatingly ridged with about thirteen or fourteen very strong, single or dichotomous ridges, the sides of which are usually cut by numerous deep oblique sulci ; the ridges are

highest at the base, where they terminate adruptly; osseous base a little wider than the crown. Diameter of base three or four lines."—(*M'Coy.*)

The specimens forming the subjects of this description are in the Woodwardian Museum at Cambridge. They were obtained from the Mountain Limestone of Derbyshire and are stated by Professor M'Coy to be tolerably abundant in that locality. I have not seen specimens in other collections or from other localities.

Two species have been found in the Coal Measures of Belleville, Illinois ("Geol. Illinois," Vol. II., p. 70, *et. seq.*); one of very large size from the Burlington Limestone of Iowa, in America ("Geol. of Illinois," Vol. IV., p. 369). Specimens were discovered in the Devonian rocks by M. Trautschold, who named them Ostinaspis and considered that they were dermal tubercles, allied to those of the Rays; and M. de Koninck has described a species from the Mountain Limestone of the neighbourhood of Tournai, on the borders of Belgium ("Fauna du Calc. Carb. de la Belgique." p. 37).

Prof. M'Coy considered that the teeth of Petrodus approached more nearly in microscopic structure to those of the living Cestracion than any others, and this opinion appears to be shared by M. de Koninck, with regard to the Belgian specimens. Messrs. Newberry and Worthen, who have described the American forms, in accordance with a suggestion made by Prof. Agassiz, consider that these bodies were not teeth, but the dermal tubercles of a fish probably resembling some of the living Rays or of the *Squalaraja polyspondyla* figured by Prof. Agassiz from the Lias of Lyme Regis ("Poiss. Foss.," Vol. III., pl. 43). The reasons on which this supposition is based are, that the base is very thin and very flat, much more so than in any Cestracionts, and too much so for the requisite solidity and stability of teeth of which the function was the crushing of resistant substances. The base is also laminated on every side forming a thin, sharp, finely crenulated edge, which would prevent the teeth being in contact with each other, and in this respect offer a strong contrast to other fossil forms of Cestracionts.

The teeth of Petrodus bear a close resemblance to those of Pleurodus from the Coal Measures. The latter are thin, the base is very small, and deeply concave in some instances, the edges are pectinated, and the surface is deeply ridged; in all these respects bearing a close analogy with the teeth of Petrodus; and as the Pleurodus is undoubtedly a tooth, it may be assumed with considerable certainty that Petrodus is a tooth also.

Genus—Ramphodus, Davis.

Teeth, medium size, laterally, triangularly elongated; lateral prolongations unequal. Crown acuminate, recurved posteriorly; antero-posterior diameter, small; coronal surface minutely punctate. Tooth bifurcates at right angles, onefourth its greatest length from the apex; base small.

Rhamphodus dispar, Davis.

(Pl. LI., figs. 17, 17*a*.)

Teeth, Length from the pointed crest of the crown to the left lateral extremity is 1·1 inch: opposite side is ·7 inch. The crown is produced and curved towards the posterior face, presenting something like the appearance of a bird's beak. Lateral surfaces compressed, their junction constituting an obtuse median ridge. There are no minor lateral prominences. The surface is uniformly covered with minute pustulate projections. At a distance of ·3 inch from the apex, the crown bifurcates rectilinearly with an obtusely-rounded angle, forming two lateral extensions of unequal length as stated above. The lateral extremities are thin, somewhat angular, with a well defined ridge extending along the posterior surface. The shorter one terminates in a projecting rounded boss: the longer in a backwardly-curved obtusely-pointed extremity. Anterior surface thin, partly hidden by matrix. Posterior surface, angular and deeply grooved vertically, as though by rubbing against an opposing tooth. Lateral extremities below the bifurcation, are about ·1 of an inch in thickness, being one-half the breadth. The basal portion of the tooth is only visible in the centrally divided portion, and is not large.

Its nearest affinity seems to be with Helodus, but it differs from that genus so materially in the pointed recurved character of the crown, in its pyramidally acuminate form, and the deeply divided base, that it is extremely doubtful whether it can have occupied an equivalent position to the teeth of Helodus. It also bears a superficial resemblance to an American form from the St. Louis limestone which was described by Dr. Leidy under the name of *Chomatodus venustus* ("Trans. Am. Phil. Soc. Philadel.," Vol. XI., pl. v., figs. 19–21). The species was afterwards included in the genus Venustodus with the specific name Leidyi, by Messrs. St. John and Worthen ("Palæon. of Ill.," Vol. VI., p. 350, pl. ix., figs. 1–4). The teeth included under this definition are of two kinds, one presenting a similar angular form with pointed crest, to those described above, the second form is smaller and only slightly arched in outline. The first form only exhibits any relationship with the Armagh specimen and it is very probable that it is merely accidental: *Venustodus leidyi* differs from the tooth now described in having an acuminate apex to the crown without curvature, in the lateral extensions of the crown being equal in length, and in the lateral expansions being occupied by a variable number, between ten and eighteen, of delicate, though well defined, denticulations: the crown is also encircled by a continuous belt of coronal folds, and the base forms a relatively narrow plate, nearly co-extensive with that of the crown.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Genus—Lophodus, Rowanowsky.

Lophodus—H. Rowanowsky, 1864. "Bull. d. l. Soc. Imp. des Nat. de Moscou," p. 160.
Helodus (*partim*)—Agassiz, and others.

Teeth, generally much broader than long, median surface produced to form a conical summit; root compressed and regularly striated. The surface of the crown is covered with enamel, finely punctate. The form is not ordinarily symmetrical; occasionally, irregularly contorted. The anterior basal margin is produced and forms a sharp edge. The transverse section "exhibits the form of a nail with a conical head."

M. H. Rowanowsky describes the microscopical structure as being very uniform in the different species, it is characterised by the union of the central medullary canals, relatively large and irregular, giving rise to a number of smaller canals, generally bifurcating, and radiating towards the surface where they are externally visible as minute pores; all the canals branch into a large number of minute and short, dentritic calciferous tubes.

The genus Lophodus was created by M. Rowanowsky for the reception of teeth of fishes in which the crown of the tooth is more or less conical with a concavity of the base which corresponds to the convex surface of the crown.

The root is deep but not thick. The teeth comprised in the genus Lophodus were described by Prof. L. Agassiz as Helodus, and other authors to the present time have followed, for the most part, his initiative. The species *H. mammillaris* and *H. didymus* of Agassiz are referred to the new genus, whilst *H. planus* and *H. turgidus*, Agass., are considered as the types of the old genus Helodus.

It is questionable to what extent the re-distribution of M. Rowanowsky may prove correct. *Helodus planus* was considered by the late Prof. Agassiz, and is now generally accepted as belonging to the same fish as *Psephodus magnus*. And the somewhat miscellaneous group of *Helodus turgidus* has since been revised and amended. There is also the important discovery described by Messrs. Newberry and Worthen, ("Palæont, Illinois," Vol. II., p. 88.) of the teeth of Helodus and Cochliodus being found impacted together as to leave no doubt that they originally belonged to the same fish. Some of the teeth so found, as for example, the one represented in pl. VI., fig. 4a, *op. cit.* bears a tolerably close resemblance to the typical species of Lophodus figured by M. Rowanowsky. On the other hand, if the genus be confined to teeth which have occupied a similar position and have been arranged in the same way as Orodus, or the recent Cestracion, there is every possibility that it may prove a good and satisfactory genus.

Messrs. Newberry and Worthen instituted the same name in 1870 ("Survey of Illinois," Vol. IV., p. 360) to designate a genus of fossil fish which name has since been transformed by Messrs. St. John and Worthen into Agassizodus ("Palæont. Illinois," Vol. VI., p. 311).

Lophodus lævissimus, Agassiz (sp.)

(Pl. LI., figs. 18, 18*a*, 18*b*, 18*c*.)

Psammodus lævissimus—		L. Agassiz,	1833.	"Poiss. Foss.," Vol. III., pl. xiv., figs. 1–11.
,,	,,	Sir. P. Egerton,	1837.	"Catal. Foss. Fishes."
Helodus	,,	L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., p. 104.
,,	,,	J. E. Portlock,	1843.	"Report on Londonderry, &c.," p. 461.
,,	,,	L. G. de Koninck,	1844.	"Disc. des Anim. Foss. du terre Carb. de Belg.," p. 614, pl. lv., fig. 3, (pl. liii., fig. 9, excluded).
,,	,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pl. 3, p. 340.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 583.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 647.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 328.
,,	,,	F. J. Pictet,	1854.	"Traitè de Palæont.," Vol. II., p. 267.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 630, pl. iii., fig. 17.
,,	,,	E. d' Eichwald,	1860.	"Lethæa rossica.," Vol. I., p. 1546.
,,	,,	J. Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	Young and Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., p. 100, Supt. p. 72.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devonico.-Carb.," p. 357.
Lophodus	,,	L. G. de Koninck,	1878.	"Fauna du Calc. Carbonif. de la Belgique," p. 33, pl. iv., fig. 6.

Teeth, small; transverse diameter equal to three times the antero-posterior one; crown elevated into a simple obtuse cone, of which the base occupies the centre of the tooth; the crown is gradually depressed and tapers from the central cone to the extremities, which are feebly truncated. Surface uniformly punctate or smooth. The root is slightly less in depth than the height of the crown and thinner, it is directed obliquely forwards, and separated posteriorly from the crown by a small groove. The inferior surface of the root is slightly concave. It is composed of a coarsely striated, bony structure.

The specimens figured by Agassiz ("Rech, sur les Poiss. Foss.," Vol. III., pl. xiv., figs. 1–11) belong in all probability to this species, the remaining figures do not.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Lophodus gibberulus, Agassiz (sp.)

(Pl. LI., fig. 19.)

Psammodus	gibberulus—	L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., pl. xii., figs. 1, 2.
"	"	P. de G. Egerton,	1837.	"Cat. of Fossil Fishes."
Helodus	"	L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., p. 106.
"	"	J. E. Portlock,	1843.	"Geol. Rept. Londonderry, &c.," p. 461.
"	"	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pl. 3, p. 340.
"	"	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 583.
"	"	"	1849.	"Enumerator Palæont.," p. 647.
"	"	J. Morris,	1854.	"Cat. Brit. Foss.," p. 328.
"	"	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II. p. 267.
"	"	E. d' Eichwald,	1860.	"Lethæa rossica," Vol. I. p. 1546.
"	"	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
"	"	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 357.
Lophodus	"	L. G. de Koninck,	1878.	"Fauna du Calc. Carbon. de la Belgique," p. 35. pl. iv., fig. 7.

Teeth, broadly elongated, crown elevated into two cones; length ·65 inch, breadth ·25 inch, height of central cone ·25 inch. Crown; central cone obtusely rounded, anteriorly depressed, longitudinal surface produced so as to form a ridge like prominence. A deep sulcus separates the central cone from a smaller one on the left side which partakes generally of the characters of the larger elevation; the lateral extremities of the coronal surface are obtuse, about the same breadth as the base of the central cone, and are recurved upwards producing the appearance of a small cone one on each side. Anterior surface slightly convex, and one-third deeper than the posterior. Coronal surface enamelled, smooth along the apex, deeply punctate elsewhere. Base large, extending laterally beyond the surface of the crown; anteriorly it descends obliquely with the surface of the crown, posteriorly it is deeply concave; roughly striated and fibrous; a ridge extends along the anterior and posterior surfaces separating the crown from the base, it is occasionally slightly serrated. Specimens found in the Limestone of Belgium, and ascribed to this species by M. de Koninck, are stated to have both lateral extremities with an equal number of secondary cones, in this respect differing slightly from those described above.

The type specimen figured by M. Agassiz in the "Poissons Fossiles" is slightly imperfect at one extremity. It is from the Limestone of Bristol.

Formation and locality: Mountain Limestone, Armagh; Bristol; Yorkshire.
Ex coll. Earl of Enniskillen.

Lophodus mammillaris, Agass, (sp.)

(Pl. LI., fig. 20.)

Helodus mammillaris	—L. Agassiz,	1838.	"Poissons Fossiles," Vol. III., pp. 173 and 383.
,, ,,	J. E. Portlock,	1845.	"Rept. Geol. Londonderry," p. 461.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 341.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 583.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 647.
,, ,,	J. Morris,	1854.	"Cat. of Brit. Foss.," p. 328.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 631, pl. 3 I., fig. 16.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	Young & Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., Supt., p. 72.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devon Carb.," p. 357.
Lophodus ,,	L. G. de Koninck,	1878.	"Fauna du Calc. Carb.," p. 35, pl. iv., figs. 9, 10, 11.

Teeth, "crown very much elongated, narrow, abruptly pointed at each end, having a moderately large, rounded, abruptly-tumid gibbosity, rather nearer to one end than the other, and sometimes having an obscure bead-like projection, with an underlying vertical area, over one of the long lateral margins ; short end even and pointed ; long end with one or two very faint, small, secondary gibbosities. Surface of the large prominent boss coarsely granulo-punctate, the punctations being finer, and often obscured by a polished surface of ganoine on the ends. Average length seven lines, greatest width two lines, height of crown one and a half lines."—(*M'Coy.*)

M. de Koninck in describing this species gives as a characteristic distinguishing it, the possession of two small pointed tuberosities, one in front of, and the other behind, the basal portion of the median cone ; these he regards as separating the species from *Lophodus gibberulus* and *L.* (*Orodus*) *subteres*, which offer no trace of such tubercles. Professor M'Coy considers that this species may be found eventually to belong to either one or other of the species named, or that the three may be only one species. There appears no reason to doubt that M. de Koninck is correct.

The specimens were named by Professor L. Agassiz, it being his intention to describe them in a supplement. The latter unfortunately never appeared.

Formation and locality : Mountain Limestone, Bristol and Armagh.
Ex coll. Earl of Enniskillen.

Lophodus didymus, Agass.

(Pl. LI., figs. 21, 21*a*.)

Helodus didymus—	L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., pp. 173 and 383.
" "	J. E. Portlock,	1845.	"Rept. Geol. of Londonderry," p. 461.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3. p. 341.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 583.
" "	"	1849.	"Enumerator Palæont.," p. 647.
" "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 328.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 630, pl 3 I., figs. 18, 19, 20.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
" "	H. Rowanowsky,	1864.	"Bull. Soc. Imp. des Nat. de Moscou," p. 162, pl. iv., fig. 23.
" "	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 357.

Teeth, "Crown of tooth usually much elevated in the middle into a very prominent cone, more or less deeply notched at the apex, and having from that notch a more or less distinct sulcus extending towards the base of the crown, the border of which is elevated in the middle, particularly the posterior side close to, or vertically over which, the double apices of the cone usually incline. Surface, coarsely granulo-punctate, most so on the end of the middle cone, leaving the ends of the tooth nearly smooth (the granules being closed and elevated in the unworn tooth, but impressed punctate in old ones), width of average or rather small specimen four lines, height two and a half lines, but sometimes more, and often less."—(*M'Coy.*) The root is small, compressed and vertically striated.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Lophodus reticulatus, Davis.

(Pl. LI., fig. 22.)

Teeth, transverse diameter 1·3 inches; antero-posterior diameter ·3 of an inch in the widest median portion. Crown generally depressed, produced to form a median cone with a large secondary cone on each side and smaller intermediate ones. Principal cone situated nearer one end than the other, obtusely pointed, broader laterally than from front to back: a carina extends from central cone on each side, from which rise the lateral ones similar in character to the median one; lateral terminations of crown truncate. Surface of cones, smooth, punctate; anterior and posterior surface expanded and depressed, reticulate; posterior margin produced and forming a thick and rounded ridge. Base, hidden by matrix.

The characters of the type specimen of this species are somewhat indeterminate. Its surface possesses a median ridge with cones which ally it to Orodus, whilst the

antero-posteriorly expanded base of the crown gives it a slightly Helodont character. It may be found to occupy an intermediate position, at present it is included in the genus Lophodus.

Formation and locality: Carboniferous Limestone, Wensleydale, Yorkshire.
Ex coll. William Horne, Esq., Leyburn.

Lophodus serratus, Davis.

(Pl. LI., figs. 23, 24.)

Teeth, small, narrow; transverse diameter ·6 of an inch, antero-posteror diameter ·12 of an inch. Crown ascends from each lateral extremity to the central cone, latter pointed and somewhat beak-like with a slight curvature posteriorly; sub-median ridge descends from the apex of the central cone, along each lateral prolongation from which spring eight small subconical tubercles on one side and ten on the opposite one; tubercles equidistant, and along with the central one uniformly punctate. Anterior surface of crown, convex, smooth near the base. Posterior surface concave, with a series of enamelled folds extending across the tooth parallel with its margin.

This species is distinguished from *L. mammillaris* (Ag.) to which it otherwise bears considerable resemblance by the tuberculation of the median coronal ridge.

Formation and locality: Carboniferous Limestone, Wensleydale.
Ex coll. Wm. Horne, Esq., and Reed collection, York Museum.

Lophodus bifurcatus, Davis.

(Pl. LI., figs. 25, 25*a*.)

Teeth, small; transverse diameter across base ·5 of an inch; height ·4 of an inch. Crown consists of large, obtusely subangular, obliquely inclined convex surface; with a greatly depressed, slightly twisted, prolongation of the lateral extensions narrowing to subacute horizontal extremities. Anterior margin prominent; surface of crown slopes backwards to the posterior margin, which is much elevated; basal margin of crown projects beyond the roots. Surface uniformly punctate. Root, short, extending to the termination of each lateral extension of the crown, open porous structure.

This unique and peculiar tooth is provisionally placed in the genus Lophodus, resembling in some important respects the teeth included in that genus, but the peculiar anterior-posterior slope of the coronal surface and the deep lateral extensions of the enamel somewhat approach the character of the genus Ramphodus, but in this instance the lateral extensions are equal in length, those of Ramphodus being unequal and the apex of the crown is not pointed as in that genus.

Formation and locality: Carboniferous Limestone, Wensleydale.
Ex coll. Wm. Horne, Esq., Leyburn.

Lophodus levis, Davis.

(Pl. LI., figs. 26, 27.)

Teeth, median or small, varying from ·6 in transverse diameter and ·2 inch antero-posterior diameter to one-third that size. Crown, variable in form, raised to form a sub-median cone; a ridge descends from the central cone on each side situated on the posterior surface of the middle line; extremities subquadrate or very obtusely rounded; crown surface enamelled and punctate; anterior and posterior basal margins of crown, prominent, forming a sinuous ridge, much elevated in centre.

Base short, less extensive than the crown, open porous structure.

This species is much wider from back to front than *L. serratus*, and the transverse ridge is smooth and without serrations. An example is figured showing four teeth in their natural position, which appear to belong to this species though they are not quite so broad in proportion to the width as the larger specimen.

Formation and locality: Mountain Limestone, Richmond.
Ex coll. Reed collection, York Museum. William Horne, Esq., Wensleydale.

Lophodus sinuosus, Davis.

(Pl. LI., fig. 28.)

Teeth, medium size; crown, nearly an inch across, and ·25 of an inch from front to back, peculiar sigmoidal form, right lateral extremity sub-quadrate, depressed, surface raised to form a single cone, about one-third the distance from the extremity. Cone with broad, obtuse antero-posterior ridge; left prolongation of surface level, anterior and posterior margins slightly convergent for a distance equal to the length of the right extremity, remaining portion extends at an angle of 45° backwards and is rapidly acuminate. Surface smooth and punctate, without lateral ridge. Base equal in depth to the height of the crown with the usual characters.

This peculiarly shaped tooth, with others of similar but not exactly the same form, appears to differ from any previously described. It is quite possible that some of the forms now described as separate species may be discovered to be modifications of only one or two, but until better specimens are obtained it will be premature to correlate them.

Formation and locality: Mountain Limestone, Richmond, York.
Ex coll. Reed collection, York Museum.

Genus—Diclitodus, Davis.

Teeth, small. Crown with two subequal prominent cones separated by a deeply concave depression of the surface. Base of the crown conforming with the superior surface. Root sinuously parallel and co-extensive with the base of the crown.

Diclitodus scitulus, Davis.

(Pl. LI., figs. 29, 29*a.*)

Teeth, small. Crown consisting of two cones; transverse diameter ·3 of an inch, height ·2 of an inch. Cones, equal in size, separated by a circular hollow equal in depth to the external lateral margins of the cones and about one-half the entire height of the tooth. A ridge extends from each lateral extremity transversely across the tooth, having slight indications, when magnified, of tubercles. The apex of each cone is obtusely rounded, smooth and enamelled; surface uniformly punctate; the basal margin of the crown is sinuous, conforming to its superior outline, it consists of a prominent, slightly recurved ridge, separated by a sulcus from the upper surface. Root, equal in depth to the height of the crown; close, fibrous structure, parallel with the sinuosity of the base of the crown and two rows of deep regular punctures, with an intermediate ridge; attenuated below; under-surface similar in outline to the base of the crown.

Several examples of this peculiar tooth have been found in the Limestones of Wensleydale along with some other unique forms. It appears to resemble in structure the teeth of Orodus, but its double biconal arrangements separate it from any other genus hitherto described.

Formation and locality: Carboniferous Limestone, Wensleydale, Yorkshire.
Ex coll. William Horne, Esq., Leyburn.

Group.—Cochliodontidæ, Owen.

Cochliodontidæ—R. Owen, 1867. "Geological Magazine," Vol. IV., p. 59.

A well defined group of fish-palates, with many characters in common, is represented in the Carboniferous series of rocks almost exclusively. The central genus of the group is Cochliodus, and branching with various modifications are the genera Streblodus, Sandalodus, Deltodus, Psephodus, Deltoptychius, Pæcilodus, Xystrodus and Tomodus. Before proceeding to describe the peculiar characteristics of this group, it may be worth while to briefly summarize the opinions, classificatory or descriptive which have already been published. The remarks applied by the late Professor Agassiz to the teeth of Placoid fish in general are especially true of this group. After pointing out the imperfection of the actual knowledge of cartilaginous fishes, he remarks that surprise should not be felt at the little progress made in the study of the fossils pertaining to this group of animals. The difficulties attending the determination of the teeth of sharks and rays, which are

frequently the only parts of the fish preserved, and which occur throughout nearly all the strata in which fossils are found, is rendered very great, from the fact that only in a very few instances can the determination be based on a comparison of the fossil species with the existing ones. The species found in the more recent formations may be satisfactorily associated with living forms : but lower than the Tertiaries the geological affinities of the fossil fishes become more and more a matter of generalized speculation. The fishes of the secondary formations differ almost entirely from those now existing, whilst in the still earlier primary rocks, the characters exhibited by the fossils are only in rare cases comparable with living species, and in no instance is this so apparent as in the group of palates now under consideration.

Professor Agassiz originally included in his genus Psammodus all the teeth of Cestraciontes, of which the surface is neither wrinkled or reticulated, without crest, or longitudinal or transverse ridges. The forms of the teeth included in this description were very various.* The genus comprehended all the species whose crown was formed, as in Cestracion, of small vertical tubes opening on the surface and extending downwards into the tooth in the form of medullary canals ; thus defined it included :—

Psammodus gibberulus.	Psammodus contortus.
P. subteres.	P. longidens.
P. linearis.	P. reticulatus.
P. rugosus.	P. magnus.
P. porosus.	P. tenuis.

The discovery of further specimens convinced M. Agassiz that several of the palates regarded as species of Psammodus were of generic value. Their occurrence in strata extending from the Stonefield slate and clays of Shotover through the Permian and Coal Measures series to the Mountain Limestone, supported the inference that during these long periods several types of Cestracions existed, which whilst closely related in their dentition were sufficiently distinct to have constituted separate genera.

The following modifications of the genus Psammodus were therefore adopted ; without, however, being regarded either as final or more than approximately correct :—

Helodus	(Psammodus)	gibberulus and subteres, &c.
Chomatodus	,,	linearis, &c.
Psammodus	,,	rugosus, porosus.
Cochliodus	,,	contortus.
Strophodus	,,	longidens, reticulatus, magnus, tenuis, &c.

The genera Ceratodus, Ctenodus, Acrodus and Ptychodus were also associated with the above, being regarded as more nearly related to the Cestracionts than to the Rays.

* "Poiss. Foss.," Vol. III., p. 103.

The two genera, Ceratodus and Ctenodus, were correctly regarded as materially differing from the dentition of Cestracion, each tooth occupying a ramus of the upper or lower jaw respectively; those of each jaw being attached to each other at the median line.

After a consideration of the microscopical structure of the teeth, they are divided into three groups. The *first*, comprehending the genera Ptychodus, Strophodus and Acrodus, of which the existing Cestracion may be taken as the type; it is distinguished by an outer layer of enamel on the dentine forming the surface of the crown. The *second* group is composed of the genera Chomatodus, Cochliodus, Psammodus, and Ceratodus, and in this the layer of enamel is absent, and the medullary canals open on the surface of the tooth. The *third* group is formed of the two genera Ctenodus and Ctenoptychius; they are characterized by the possession of an almost homogeneous surface of dentine which only exhibits occasional traces of the medullary canals or tubes. Not having a tooth of Helodus at his disposal, Agassiz was unable to assign its position but considered it would probably fall into the second group.

Prof. Owen ("Odontography," p. 49, *et seq.*) accepts the classification of Agassiz, and regards the existing Cestracion of the Australian seas as the only existing representative of the fossil genera indicated by that ichthyologist. Hybodus, Orodus and Petalodus are also included in the family. Prof. Owen disagrees with Prof. Agassiz as to the microscopical structure of the teeth and contends that the medullary tubes have no relation to the punctate impressions of the enamelled surface. The "tubes always terminate at a short distance from the surface of the tooth, either by anastomosis or by sub-division into other tubes of such extreme minuteness that the combined diameters of five hundred of them would barely equal the breadth of a single superficial punctation. These impressions on the teeth of Psammodi, like the transverse ridges of those of the Ptychodi, are consequences of the conformation of the original matrix, and can be regarded only as adaptations conformable with the habits and food of the extinct species; and as they are not due to a certain tubular structure, so neither can they be viewed as evidence of such structure when it has not otherwise been proved to exist."

With regard to the extinct genus Cochliodus, Prof. Owen remarks that it presents a very interesting modification, resembling in structure those of Psammodus. Here the jaws are paved with teeth arranged in a few oblique contorted series, as in the Cestracion, but a single tooth occupies the space covered by an entire row in the existing Australian genus. In the specimen figured ("Odontography," pl. 222, fig. 1.) there are three of these large contorted dental plates in each ramus of the jaw. "The microscopic structure of these large teeth closely resembles that of the true Psammodus; the medullary canals have the same straight, sub-parallel course, and sparing dichotomous sub-divisions, but they are relatively wider, and are separated

by interspaces of less breadth. The calcigerous tubes are also wider at their origin; they come off not quite at right angles to the medullary canal, but are slightly inclined to the grinding surface of the tooth; they quickly ramify, sending off their branches at nearly right angles, and are less flexuous in their course than in the Petalodus; they dilate into angular cells at many parts of the mid-space between the medullary canals."

M'Coy ("British Palæozoic Rocks and Fossils," p. 621) differs from Profs. Agassiz and Owen, and considers that there can be no real affinity between the genus Cochliodus and Cestracion or any of the Sharks; for, first, the teeth are supported on a strong bony jaw as in Placodus (which also agrees in having three teeth on each side of the lower jaw, although differing in microscopic structure); secondly, the enrollment of the teeth is on the outside of the jaw, and not as in sharks, on the inside to allow the succession of teeth from behind forwards; and finally, a broken tooth of another species, the *C. oblongus*, enables me to prove the succession of the teeth was not by revolution from behind, as in the Plagiostomous fishes, but vertically from below upwards, as in the Pycnodonts (*op. cit.*, pl. 3 H, fig. 19 and 3 I, figs. 28.) Prof. M'Coy describes four genera, in addition to *C. contortus*, described by Agassiz in the "Poissons Fossiles," viz., *C. acutus*, *C. magnus*, *C. oblongus*, and *C. striatus*. These had been previously named by Agassiz, but not described ("Poiss. Foss.," Vol. III., p. 174). The type specimens are in the Enniskillen collection.

The genus Pœcilodus, also instituted by Agassiz, was considered by M'Coy to be only a sub-genus of Cochliodus. The number and form of the teeth, with the strong inrollment, particularly of the median tooth over the outer part of the jaws seeming to be the same in both, "the only tangible difference of the present teeth being the more or less distinct longitudinal ridges which cross the teeth parallel to the inner margin." In addition to *Pœcilodus jonesii* and *P. transversus*, *P. obliquus*, *P. parallelus*, and *P. sublævis*, named by Agassiz ("Poiss. Foss.," Vol. III., p. 174), M'Coy described two others, *P. aliformis* and *P. foveolatus*.

In the year 1858, Prof. Agassiz was led to reconsider and revise his classification and arrangement of the Cochliodont group of palates. Since the publication of his great work on fossil fishes, in 1840–3, an immense number of specimens had been discovered, and it was, in consequence, possible to form a much clearer conception of the actual characters and relationships of the several groups forming the entire fish-fauna of the Mountain Limestone. The forms, at first considered as species of Cochliodus, were not only found to be persistent, but developed characters, shewn in largely increased numbers of specimens, which proved their several peculiarities to be of generic importance. The result was, that M. Agassiz divided Cochliodus and Pœcilodus into the genera tabulated in the following list, and intended to redescribe the whole group. Adverse circumstances intervened,

and his premature death finally prevented all chance of the work being completed by his master mind and hand :—

Cochliodus contortus	=	Cochliodus contortus.
C. magnus	=	Psephodus magnus.
C. oblongus	=	Streblodus oblongus.
C. acutus	=	Deltoptychius acutus.
C. striatus	=	Xystrodus striatus.
Pœcilodus angustus	=	X. angustus.
P. jonesii P. transversus	=	Pœcilodus jonesii.
P. obliquus	=	P. obliquus.
P. sublævis P. parallelus	=	Deltodus sublævis.

With the addition of other species, the arrangement in the second column will be adhered to in the following pages.

In 1867, Prof. Owen published a paper in the "Geological Magazine" (Vol. IV., p. 59) on the mandible and mandibular teeth of Cochliodonts, in which he considers "that the extinct crushing sharks of the Mountain Limestone period, though instructively represented by a lingering member of a once numerous section of Chondropteri, must be relegated to a distinct though conterminous family, for which I proposed the name of Cochliodontidæ, from what may be regarded as the representative genus, Cochliodus, Ag." Specimens of the mandibles and teeth of *Cochliodus contortus*, Ag., (including *Tomodus convexus*, as described by Owen) and *Streblodus oblongus*, Ag., are described, with the result that Prof. Owen considers that the relative positions of the teeth of each ramus of the jaw with its symphysis corresponds with the parts of the mandibular rami of Cestracion containing the anterior crushing teeth, and that they afford no ground for assuming that the symphysis was prolonged, as in Cestracion, for the support of conical or any other teeth. The mandible increases in depth posteriorly but diminishes in breadth, indicating a shape of jaw like that in Cestracion. The structure of the bone resembles that of the better ossified parts of the chondrine of plagiostomous fishes. In another example in the Woodwardian Museum, Cambridge, the reverse of the above is seen, in which the posterior end of the right ramus of the mandible is of little breadth and depth, but it gains in both, and chiefly in the latter dimension, as it approaches the symphysis, and there rapidly acquires great breadth and thickness. From the oppositeness of these descriptions it may be inferred that the soft cartilaginous supports of the teeth, during fossilization have been more or less subjected to pressure or other circumstances which have modified the form of the jaw, but at the same time the important fact is deduced that the teeth of Cochliodonts consisted of teeth whose convolutions were attached to, and partially embedded in a thick cartilaginous

mandible, a part of which extended inwards from the jaws and formed a covering or base for the palates which may or may not have had other teeth attached. None of the present specimens exhibit any trace of other teeth having been so attached, and though examples have been discovered by American palæontologists in which the teeth of Cochliodus and a species of Helodus have been found associated in such a manner as to lead to the inference that they belonged to the same fish, this evidence has not hitherto been confirmed by any British species.

As already stated, Dr. Günther ("Study of Fishes," p. 329), places the Cochliodonts in his family Cestraciontidæ, along with Ctenoptychius from the Devonian; Psammodus, Chomatodus, Petrodus, Polyrhizodus, &c., from the Carboniferous series; and Strophodus, Acrodus, Thecodus and Ptychodus, from the Trias and Chalk.

Having in the foregoing brief resumè glanced at the classification of the group of fishes represented by the fossil Cochliodus adopted by the several authors enumerated, it is proposed to describe, in such detail as may be necessary, the dentition of the members of the group which it is possible satisfactorily to interpret. The elucidation of the subject is, however, attended with many difficulties, and it is only tentatively that the attempt is now made: the complete reconstruction, on a thoroughly sound basis, of the dentition of this large and important group of fishes must depend in a very great measure on the acquisition of more perfect specimens. Much information can be gathered from the study of the unique collection of this group collected by Lord Enniskillen, and considerable light has been thrown on the genus Cochliodus by some magnificent specimens gathered by American palæontologists from the Carboniferous Measures so largely developed in Illinois and Ohio, but the complete and perfect dentition of any single fish has not yet been discovered in a state sufficiently well and regularly preserved to warrant the statement that it is perfectly known and consequently comparable or otherwise with that of existing fishes.

The teeth of the group of fish remains, for which Prof. Owen has proposed the name Cochliodontidæ, differ much in the details of their form and arrangement, but they possess the chief character in common, which is the distinguishing feature of the group, viz:—that they grow or increase in size, not as in most fishes, by the old and worn teeth being replaced from behind or below, but by continuous or repeated additions to the inner or posterior margin of the surface of the tooth, so that the same tooth is always increasing in size with the growth of the fish, and assumes an inrolled or convoluted form. An analogue of this peculiar growth is seen in that of the testaceous covering of the mollusca, which, though it assumes a wonderful variety of forms increases in size by the addition of repeated layers to the open margin of the shell. A transverse section of the teeth of Cochliodus, Streblodus, Deltodus or Deltoptychius, exhibits a more or less helecine involution, whilst those of Psephodus, Pœcilodus or Xystrodus, though flatter, increase by the radial expansion of the triturating surface.

The dentition of the genera Cochliodus and Streblodus appears to have been very similar, consisting of a series of three deeply inrolled teeth on the ramus of each jaw. The jaws were cartilaginous though it is probable that the cartilaginous substance was to some extent permeated by minute grains of ossified matter, similar to the chondroid bony structure of some of the plagiostomous fishes. The specimens described by Prof. Owen, already referred to, and those to be described in further pages of this work, do not indicate that other teeth occupied the intermediate space between the two lateral series covering the rami of the jaws. Messrs. Newberry and Worthen have, however, described specimens from the Keokuk limestone of Illinois ("Palæont. Illinois," Vol. II., p. 89.) from which it appears that the fish had, in addition to convoluted teeth of similar form to Cochliodus, a number of smaller teeth resembling, if not identical with, those of the genus Helodus.

The dentition of *Psephodus magnus*, Ag., differs considerably from that of Cochliodus or Streblodus. The teeth are much flatter and exhibit a very slight curvature, especially in the larger teeth. Combined with great variety in outline and form, there is a general similarity in the superficial appearance of the teeth as well as in the denticulation of the margins. The examination of the magnificent suite of specimens in Lord Enniskillen's collection has suggested the following deductions as to the arrangement of the dentition of this genus.

Many of the teeth are smoothly concave on the under surface, presenting the appearance reproduced in Pl. LV., fig. 1; the concavity is in the direction of the line of growth, expanding in the usual manner from a comparatively narrow base to a widely expanded opposite margin. In Psephodus it will be observed that the teeth appear to have increased in size along the margin which enveloped the outer side of the jaw. The posterior edge of the largest tooth of the set is more or less rounded; the anterior edge is comparatively straight and fits to the second or median tooth. The concavity or channel is wider at the rounded extremity of the tooth and gradually diminishes towards the straight anterior margin. The next or median tooth in the series exhibits similar characters, the channel still continues to diminish in diameter, being at the widest part equal to the narrowest of the previous tooth, and the convolution extending from the inside to the outside of the jaw. The third tooth was situated between the median one and the symphysis of the two rami of the jaws, it converges rapidly in diameter towards the symphysis, and the channel on the underside becomes attenuated almost to a point. In front of this there is a long narrow tooth (Pl. LV., fig. 6.) whose surface is raised in the form of several obtusely pointed cones. There is no indication that similar narrow teeth were attached to either the median or large posterior teeth and it seems probable that they were attached in front of the anterior pair of teeth, which are comparatively narrow, for the purpose of seizing the objects on which the fishes fed with greater firmness and security. In addition to the long and narrow tooth on the external margin of the anterior one, there were others which were ranged from its internal

surface backwards into the mouth. A series of three of these is represented in Pl. LV., fig. 4. They probably, judging from their form and arrangement, occupied the space between the median line of the palate and the large teeth arranged on each ramus of the jaw. Whether the teeth were similarly arranged in both jaws it is impossible to say, but it appears probable that they were; the only difference observed in the teeth being in the disposition of the coronal surface; in some specimens the crown is worn by attrition quite hollow, whilst in others it is rounded and convex though evidently much used.

The above observations may perhaps be summarized as follows: that a row of three principal teeth increasing in size backwards were attached to each cartilaginous ramus of the jaw; that the diameter of the jaw, as indicated by the groove or channel on the under-surface of the teeth, diminished towards the symphysis; that a long, narrow tooth was placed in front of the anterior one, and that a series of at least three Helodoid teeth were placed behind it, extending over the palate and increasing in size backwards.

The dentition of Deltodus, Deltoptychius, Pœcilodus, and the remaining genera were arranged, with varying modifications to suit their several forms, in approximately close relationship to those already mentioned. The form of the teeth in the upper and lower jaws respectively in Deltoptychius and Deltodus somewhat resemble each other in general characters but are altogether distinct in detail. The teeth of *Deltoptychius acutus* were probably arranged very similarly to those of Cochliodus, being closely related in form so far as the teeth of the lower jaw are concerned. The teeth of both the upper and lower jaws are hollowed on the inferior surface and show the direction in which they were attached to the jaws. The teeth of Deltodus and Deltoptychius here ascribed to the upper jaw, appear to have had only one tooth to each ramus of the jaw, in this respect being similar to Ceratodus. It is possible that both jaws of Pœcilodus were furnished in a similar way.

It is interesting to note that Professor Agassiz ("Poiss. Foss.," Vol. III., p. 113), speaking of the genus Cochliodus, describes a jaw with the teeth attached in their proper places. The specimen was formerly in the collection of Captain Jones, and is now in that of the Earl of Enniskillen by whom it was placed at the disposal of Professor Agassiz; it is represented in pl. 19, fig. 14, of the "Poissons Fossiles," and is regarded as being "of the greatest importance to the history of the Cestracionts of the older formations, for not only does it serve to solve all doubts on the subject of Psammodus, but I have acquired, in seeing it, the confirmation of the supposition I had formed on the subject of the genus Ceratodus, which I have always believed should be regarded as a Squalus, having only a single large dental plate, instead of several ranges of teeth upon each branch of the jaw. The fragment in question not only supports this opinion, but it constitutes a type intermediate between Ceratodus and the Cestraciontes, living and fossil." The new genus Cochliodus

"in place of having a great number of rows of teeth placed the one behind the other, in the form of large plaques more or less arched, as in the genera Acrodus and Phychodus, or in the form of a cushion of twisted spindles, as in the genus Cestracion, exhibits only a small number of teeth disposed in such a manner as to cover a large portion of the rounded surface of the dentary border of the jaw." The fragment referred to exhibits a range of three teeth on each; it has, however, the appearance of having had a fourth, which is lost. Professor Agassiz further considers it evident that the small number of teeth preserved in Cochliodus, take an intermediate place between the numerous ranges of teeth which form the fusiform palates of the genus Cestracion, and that of Ceratodus with its four teeth, one to each ramus of the jaw, and that their large contorted surfaces embraced a large space upon the jaw.

The relationship surmised by Professor Agassiz to exist between Ceratodus and Cochliodus may possibly prove correct, but the discovery of an existing species of Ceratodus in the Australian rivers by Dr. Krefft, in 1870, has proved that should such relationship be found between the two, Ceratodus will not join Cochliodus as one of a family of sharks, but that the opinions hitherto held respecting the Selachian attributes of the Cochliodonts will have to be seriously modified. There are some points of resemblance between the Cochliodonts and Ceratodus which it may be useful to point out. The skull of Ceratodus is primarily composed of cartilage, with a few ossified centres. The vertebral column is notochordal. The pectoral arch mainly cartilaginous, and the pelvic arch entirely so. Twenty-seven pairs of bony ribs. The mandibles are connected with the skull by a suspensorium, they are short, with a wide symphysis. The disposition of the teeth of Ceratodus is ascertained to be as follows :—" An osseous palato-pterygoid arch supports two palatal dental plates, whose horns or denticles project outwards, the larger and more prominent being anterior. In advance of these are two cutting teeth imbedded in the vomerine (mesethmoid) cartilage. The mandible supports a similar pair of dental plates. These are attached by their inner edges to the splenial bone, which invests the inner side of the jaw, while on the outer side they overlie the cartilaginous centre of the ramus, and to some extent the angular bone, with which they have a fibrous connection. In biting, the ridges of the dental plates interlock, though the opposed surfaces are not so accurately adjusted as altogether to prevent a sliding movement; the vomerine teeth are unopposed. All the dental plates are anchylosed to the supporting bones." (L. C. Miall, " Sirenoid and Crossopterygian Ganoids," p. 20, Palæont. Soc., 1878).

With the present knowledge of the Cochliodonts it appears probable that the dentition of some of the genera consisted of a single dental plate to each ramus of the jaws, and though the palate and mandibles were cartilaginous with partial ossification, the teeth were firmly implanted if not anchylosed. The dental plates in Ceratodus rise into external folds or ridges, the surface of the investing dentine

being punctate, with minute tabular structure. The surface of the Cochliodonts is similarly punctate and tabular in structure, and with modification it rises into external folds and ridges. So far as known, the entire skeleton of Cochliodus was more or less cartilaginous, and except in rare instances, where a portion of the mandible has been preserved, the skeleton of this group remains unknown and unpreserved.

Professor Miall (*op. cit.*, p. 26,) discusses the probable mode of growth of the teeth of Ceratodus, and concludes that "it is probable that the tooth was at first comparatively soft and vascular, that it grew, replaced the loss from wear, and changed its figure as requisite, becoming fully calcified and rigid only in the adult." After careful comparison of the teeth of Ceratodus with those of the Cochliodonts, it will be found that the teeth of the former resemble the latter to this extent, that the several ridges or denticulations radiate more or less from a central point on the smooth hinder surface of the tooth to its anterior or outside margin. It has already been shown that the teeth of Cochliodus increase in size by the growth or addition of new dental substance to the constantly expanding inner surface of the tooth, giving it a convoluted form. In some other members of the group, as in Psephodus, &c., a similar plan of growth results in a radial expansion of the surface, whilst, at the same time, it maintains a depressed and flattened surface. It is possible that the outer denticulated margin of Ceratodus increased in the same way, the teeth increasing in size with the growth of the jaws to which they were attached. The method of growth here indicated, though matter of speculation, is perhaps more in consonance with observed facts, than the idea suggested that the teeth remained in a soft state until mature. The observation made by Professor Miall, that the posterior portion of the teeth would be much worn, and that lines showing the repeated additions to the surface should be apparent, is not of great value. It may be seen in a number of any of the genera of the Cochliodonts, that in most specimens the lines indicating growth are worn off, whilst in other specimens they are distinctly visible, parallel with the margin of the newer portion of the tooth. In the case of Ceratodus, the tooth being more than usually flat, and the new surface immediately exposed to the triturating action of the opposing tooth, it will easily be conceived that the lines, if any, might be removed. With regard to the first portion of the objection, the posterior or angular portion of the teeth of Ceratodus are usually smooth, without ridges, and apparently considerably worn.

The Cochliodonts, usually regarded and described as closely related to the Cestracionts, with very great modifications of the dentary arrangement, have been found to differ from that group in the following particulars. The jaws are joined in front with a wide symphysial space, probably edentate. In Cestracion the anterior portion of the jaws is greatly produced, and is armed with a median row of sharp cutting teeth, with several others ranged on each side; the difference in the

dentition of the two groups no doubt indicates a difference in the food of the fishes. The sharp teeth in front and the crushing teeth behind, are well adapted for seizing and crushing hard-shelled animals, such as crustaceans or molluscs, which probably served as their food, whilst that of the Cochliodonts, from the flat or rounded dentition, without, so far as is known, any sharp teeth for seizing animals of any kind, leads to the inference that they were in the main, vegetable feeders.

It has been already shown that the teeth of Orodus, Agassizodus, and other allied genera bear a very close resemblance to the existing Cestracion, only diverging in one or two minor points. These forms, found along with the Cochliodonts in the Mountain Limestone, are so completely separated by their difference in form, arrangement, and adaptations to the feeding of the fish, that they afford strong evidence against their being members of the same group. The teeth of the living Cestracion and those of the fossil Agassizodus, &c., are arranged on the rami of the jaws without any intermediate palates or teeth; the dental arrangements of Cochliodus, of Psephodus, and doubtless of others, combines the lateral teeth enveloping the jaws along with other teeth which extend across the entire palate, and the gape was without doubt much wider in the latter group. These differences serve to separate the Cochliodonts from the Cestraciont sharks, whilst at the same time, it cannot be denied, as indicated by Professor Agassiz, that there is a somewhat close relationship between the dentary apparatus of this group and that of the Ceratodi.

Genus—Cochliodus, L. Agassiz, 1838.

Syn. Psammodus, (pars.) 1833. L. Agassiz.

Teeth, medium size, two or perhaps three teeth to each ramus of the jaw, remarkable for their enrolled and twisted form and the obtuse angle formed by the rami of the jaws in front. Anterior teeth small, triangular, deeply convoluted; posterior teeth larger, more or less oblong in outline, with three ridges arranged radially from the inside of the tooth outwards, surface smooth, finely punctate Base: concave, osseous, smooth.

Cochliodus contortus, Agass.

(Pl. LII., figs. 1–6)

Psammodus contortus—		L. Agassiz,	1833.	" Rech. sur les Poiss. Foss. " Vol. III., pl. xiv., figs. 16–33, and pl. xix., fig. 14.
,,	,,	Sir P. Egerton,	1837.	"Cat. of Foss. Fish."
Cochliodus,		L. Agassiz,	1838.	"Poiss. Foss." Vol. III., p. 115.
,,	,,	R. Owen,	1840.	"Odontography," Vol. II., p. 10, pl. xxii., fig. 1.
,,	,,	J. E. Portlock,	1843.	"Rept. on Geol. Fermanagh, &c.," p. 466.
,,	,,	H. B. Geinitz.	1845.	"Versteinerungsk," p. 165.
,,	,,	C. G. Giebel,	1848.	" Fauna der Vorwelt," Vol. I., pt. iii., p. 336.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 317.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 647.
,,	,,	F. A. Quenstedt,	1852.	"Hanb. der Petrefaktenk. p. 188.
,,	,,	J. Morris,	1854.	" Cat Brit. Foss.," p. 322.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267, pl. 33., fig. 31.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 622.
,,	,,	F. Roemer,	1856.	"In. Bronn Lethæa geogn.," Vol. I., p. 708, pl. ix*b*., fig. 4.
,,	,,	F. d'Eichwald,	1860.	" Lethæa. rossica.," Vol. I., p. 1547.
,,	,,	Morris and Roberts,	1862.	" Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	H. Rowanowsky,	1864.	" Bull. d. l. Soc. Imp. des. Nat. de Moscou., p. 159 pl. iii., figs. 7–10.
,,	,,	R. Owen,	1867.	"Geological Magazine, Vol. IV., p. 59.
,,	,,	Enniskillen,	1869.	"Cat. of Type Spec. Foss. Fishes," p. 4.
,,	,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glas.," Vol. III., Spt., p. 70.
,,	,,	H. A. Nicholson,	1872.	"Man. of Palæont.," p. 339, fig. 297.
,,	,,	F. Roemer,	1876.	"Lethæa Palæoz. Atlas," pl. xlviii., fig. 5.
,,	,,	Armstrong, Young, & Robertson,	1876.	" Cat. W. Scot. Foss.," p. 61.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devonio.-Carb.," p. 349.
,,	,,	L. G. de Koninck,	1878.	" Fauna du Calc. Carb. de la Belgique.," p. 57, pl. vi., fig. 14.

Teeth, sides of jaw and lateral rows of teeth converging at an angle of about 60°. Posterior tooth oblong, obliquely truncated on the outer side of the posterior end to form the posterior point; posterior edge rather abruptly raised to form the posterior oblique ridge behind, sloping into a rather deep oblique hollow, which defines the middle oblique ridge, which is much the most prominent and strongly rounded of the three ; anterior ridge coinciding with the anterior margin, very slightly raised, little tumid, separated by a moderate concavity from the steeply rounded side of the middle ridge, and forming an angle of 80° with the outer margin. Second tooth narrow, its posterior half very convex, forming a prominent, rounded ridge, rising abruptly from the posterior margin, but sloping sigmoidally to the anterior margin, which is not again relieved. Anterior teeth unknown, surface either smooth or

fine granulo-punctate by the opening of the medullary glands, average length of posterior tooth, one inch five lines, greatest width eight lines, width of middle tooth five lines."—(*M'Coy.*)

The Enniskillen collection is extremely rich in the number and beauty of the specimens of *Cochliodus contortus.* Two specimens exhibit the teeth of the right and left ramus of one jaw in natural position. They are represented on Pl. LII., figs. 1, 2. Figure 2 *a*, represents the posterior tooth and 2 *b* the second tooth, of Prof. M'Coy's description. The anterior teeth still remain unknown. A very careful examination of the specimens of single teeth as well as the more perfect ones alluded to above, and a pair of teeth in the Jones' Collection at the Geological Society of London, has failed to show any trace of teeth anterior to those shown in the figures, nevertheless the anterior margins of the second teeth of M'Coy appear to end abruptly and incompletely, and until more conclusive evidence be obtained, it may be better to withhold any opinion as to their occurrence or otherwise. The cartilaginous mass of the jaw supporting the teeth is preserved in some specimens, (see Pl. LII., figs. 1 and 6). In Pl. LII., fig. 1 it extends vertically parallel with the inside of the jaw, and is about an inch in thickness. Pl. LII., fig. 6 represents a smaller tooth, and in this case also it will be seen that the jaw extends considerably beyond the outer or inrolled margin of the teeth and is expanded into a broad, thin, plate-like mass in which the teeth are embedded.

Prof. M'Coy has asserted that teeth of *Cochliodus* (*Streblodus*) *oblongus,* Ag., have a "vertical mode of succession, the young one being distinctly visible beneath the level of the old one ("Brit. Palæoz. Foss.," p. 623, pl. 3 I., fig. 28, and pl. 3 H., fig. 19) from a transverse fracture"; "the fractured edge shows the inrollment of the outer margin of the tooth, and the whole thickness of its substance, showing the vertically tubular structure of the superficial half, and the two dense layers which form its concave under or dorsal surface. At about the thickness of the substance of the old tooth lower down is seen the young tooth, exactly concentric to it in outline and having its structure similarly displayed in the section." Specimens occur in the collection of Lord Enniskillen, which were prepared by the late Mr. Crawford, his lordship's assistant in the museum, with great delicacy and care; and these exhibit with perfect clearness the manner in which the teeth of the Cochliodonts grew or increased in size. Pl. LII., figures 4 and 6 represent respectively the larger and smaller teeth, from which it will be seen that the teeth on their initiatory stages were very small, and that they constantly and persistently increased in size by the addition of dentigerous matter to the inner margin of the dental surface, causing the helicine form of the section and the convoluted contortion of the surface of the tooth. As the growth of the tooth increased its size, doubtless corresponding with the growth of the fish, the earlier or outside convolutions became embedded in the cartilaginous mass of the jaw. It is an internal convolution of this kind which, having become detached from the main mass of the tooth, deceived Prof.

M'Coy. An examination of the specimen in the Woodwardian Museum at Cambridge has shown this to be the case, and also that the figures of the specimen given in the " British Palæozoic Fossils" are not exactly correct. The illustrations given above are from two specimens of *C. contortus*, Ag. There are others equally well prepared of *Streblodus oblongus*, Ag., which prove quite as conclusively that the teeth of Streblodus were developed in the same manner as those of Cochliodus.

The "Geological Magazine" (Vol. IV., p. 59) contains the description of a mandible of a Cochliodont by Prof. Owen. It is from the Mountain Limestone of Bristol. " Apparently the whole of the dentary part of the right ramus and the anterior half of that of the left ramus are here shown (*op. cit.* pl. III., fig. 2). The posterior end of the right dentary is of little breadth and depth, but it gains in both, and chiefly in the latter dimensions, as it approaches the symphysis, and there rapidly acquires great breadth and thickness. The lower border is thick and rounded, the outer side moderately convex; the inner side, somewhat wavy, being concave lengthwise at its middle part. The hind part of the symphysis extends back like a shelf, from below the dentigerous surface of that part of the mandible." This specimen is referred to the genus Tomodus of Agassiz, but a comparison of the specimen with the type specimens of that genus in the Enniskillen collection is at once conclusive that the one described by Prof. Owen is not a Tomodus but in all probability a crushed specimen of *Cochliodus contortus*, Agass., to which it certainly bears a close resemblance.

Formation and locality : Mountain Limestone, Bristol.
Ex coll. Enniskillen collection; Bristol and Woodwardian Museum.

Genus Streblodus, Agass. MSS., 1858.

Syn. Cochliodus—L. Agassiz, 1838. " Poiss. Foss.," Vol. III., p. 174.

Teeth, medium or small size, three teeth to each ramus of the jaw. Anterior tooth, small, convex, sub-triangular in outline; median tooth, larger, subquadrate, highly convex, margins connecting it with anterior and posterior teeth, straight, inclined at a slight angle to the longitudinal axis of the tooth. Posterior tooth, large, convoluted anteriorly and extending and expanding in diameter backwards or inwards. Crown of posterior tooth characterized by a series of two or three ridges with intermediate hollows extending radially from the anterior margin. Third or posterior ridge covers about one-half the surface of the crown. Coronal surface enamelled, punctate.

Streblodus oblongus, Agass. (MSS.)

(Pl. LIII., figs. 1–4.)

Cochliodus oblongus—	L. Agassiz,	1838.	"Rech. sur les Poiss. Foss.," Vol. III., p. 174, indet.
" "	J. E. Portlock,	1843.	"Rept. on Geol. Londonderry, &c.," p. 466, pl. xiv*a*, figs. 5, 10.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., part iii., p. 336.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 317.
" "	H. G. Bronn,	1849.	"Enumerator Palæont.," p. 647.
" "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 322.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 623, pl. 3 H, fig. 19, and pl. 3 I., fig. 28.
Streblodus oblongus—	L. Agassiz,	1859.	"MSS., Enniskillen collection."
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	R. Owen,	1867.	"Geological Magazine," Vol. IV., p. 62, pl. iii., fig. 3.
" "	Enniskillen,	1869.	"Catalogue Type Spec. Foss. Fish.," p. 8
" "	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 365.

"Posterior tooth elongate, narrow, sub-cylindrical, oblong, obliquely sub-truncate, elliptically pointed at about an angle of 45° behind; anterior margin nearly at right angles to the long axis of the tooth; anterior ridge very small, almost obsolete, scarcely defined from the equally wide flattened space between it and the second oblique ridge, which is strongly defined on each side, but narrow and only moderately convex; posterior ridge very large, exceeding twice the width of the middle ridge, separated from the middle one by a broad, moderately concave sulcus, rather more prominent than the middle ridge, broadly and moderately convex, abruptly rounded at its anterior edge, but gradually sloping towards the posterior end; length of rathen small specimens about one inch two lines, of middle ridge only two lines."—(*M'Coy.*)

Since the above description was penned a specimen has been found, consisting not only of the posterior teeth, but also of two smaller teeth on each side of the jaw, placed anteriorly to those described by M'Coy (see Pl. LIII., fig. 1); the teeth are somewhat broken and badly preserved, and the parallel position in which they are now placed is not the natural one, otherwise this unique specimen is extremely valuable in affording information as to the position and character of the dental apparatus of the fish. The jaw preserved appears to be the lower one, and consists of a pair of the large posterior teeth, described by Prof. M'Coy, one on each ramus of the jaw—two inches in length and ·8 inches in breadth. In front of these are two teeth, much smaller and not very characteristically defined in this specimen. The second tooth is about one-third the length of the large posterior one, and equal in breadth to its length. It is sub-globose in outline, the posterior margin flattened where attached to the contiguous tooth; anterior margin also compressed for attachment to the smaller anterior tooth. Crown surface obliquely convex,

whether consisting of a single ridge or more cannot be distinguished; it is much convoluted, its curvature being considerably more than a semi-circle. The two anterior teeth, which occupied a position on each side the median suture of the jaw, were about half the size of the second teeth, and appear to have been somewhat similar in form; they are not sufficiently well preserved to afford any details as to form or other characters.

The surface of the tooth is thickly covered with enamel, through which the dentigerous canals ascend from the bony substratum below, and cause the surface to present a punctate appearance. The base or root of the tooth is thick, strong, and osseous, a concavity, not so deep as the surface convexity, extends along the central axis of the tooth. In this concavity Prof. M'Coy records and figures a section of a specimen (Brit. Palæoz. Foss. pl. 3 H, fig. 19, and pl. 3 I, fig. 28), showing what is supposed to be a young tooth, exactly concentric with the old one in outline, and presenting a similar structure in section. He infers from this a vertical mode of succession of the teeth. Several teeth of this genus, in the Enniskillen collection, exhibit sections in various directions, but the appearance described by Prof. M'Coy is not presented in any instance even in the largest specimens. It is perhaps more probable, considering the inrolled or convoluted character of the teeth and the massive thickness of their bony base, that the teeth were constantly or periodically enlarged by a growth along their posterior or inside margin. Evidence supporting this view is afforded by the fact, that as the teeth increase in size the ridges and intermediate depressions radiate with always increasing breadth from the convoluted anterior margin, and at the same time the tooth increases greatly in thickness, and further, the anterior part of the tooth is most worn, whilst the recently formed posterior surface not having been used to the same extent shows very little sign of attrition.

An example is represented in Pl. LIII., fig. 4, which exhibits a portion of the jaw preserved along with the teeth of the right side of the jaw and part of the tooth of the left side. The portion preserved represents a wide expansion from the teeth inwards, deeply concave, apparently having formed a firm base to this part of the palate. Prof. Owen speaking of this specimen ("Geol. Mag.," Vol. IV., p. 62) says, "The symphysis of the jaw was shorter and the rami met there at a more open angle in Streblodus than in Cochliodus; the anterior ends of the last crushing teeth come into contact at the back part of the symphysis." The specimen is from Armagh, and forms part of the Enniskillen collection.

Formation and locality: Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Streblodus colei, Agass. (MSS.)
(Pl. LIII., figs. 5, 6.)

Streblodus colei.—	L. Agassiz,	1859.	"MSS. Enniskillen Coll.,"
„ „	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„ „	Enniskillen,	1869.	"Cat. Foss. Fishes," p. 8.
„ „	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 365.

Only posterior tooth known; it is more elongate, narrower, flatter, and has a more twisted conformation than the teeth of *Streblodus oblongus.* It averages 1·6 inches in length and ·55 inch in breadth across the posterior ridge, its widest part. Crown, with three ridges and intermediate hollows. The first or anterior ridge defines the anterior margin; it is straight, acute, narrow, and at right angles to the long axis of the tooth. The second or median ridge, extends at an angle of 45° to the first one, it is ·1 inch wide, semicircular, and rises from an almost uniformly flat or slightly concave depression extending on each side the ridge with a total diameter of half the length of the tooth. Posterior ridge, large, wide, expanding obliquely from the anterior margin of the tooth backwards. Surface enamelled, uniformly punctate; in several cases the surface is worn flat or hollowed by attrition. Front of tooth inrolled downwards, the ridges extending therefrom radially and increasing in size, especially the third one, backwards; posterior angle acutely elliptical; adpressed. Base conforms generally to the crown, thick, strong, slightly concave. Towards the posterior ridge the tooth is ·45 inch thick.

This species exhibits several well marked differences from *S. oblongus.* Its general appearance is more attenuated, and in proportion to the length it is much narrower. The surface is less convex; the posterior ridge is narrower, and extends more obliquely across the tooth. The second ridge, which in *S. oblongus* is tolerably broad with a narrow sulcus on each side, in *S. colei* is a narrow band rising from a wide depression of the surface extending several diameters of the ridge on each side.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Streblodus egertoni, Agass. MSS.

(Pl. LIII., figs. 7, 8.)

Streblodus egertoni—	L. Agassiz,	1859.	"MS. Enniskillen Coll.,"	
„ „	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101	
„ „	Enniskillen,	1869.	"Cat. Foss. Fishes, Types," p. 8.	
„ „	J. J. Bigsby,	1878.	"Thes. Dev.-Carb.," p. 365.	

Posterior teeth, small, oblong, sub-conical, deeply incurved in front; antero-posterior section of anterior portion circular. Length ·6 inch, breadth ·3 inch. Crown, anterior ridge, at right angles to longitudinal axis, forms a prominent acutely angular anterior margin, surface slopes gradually in the opposite direction forming a wide concave depression occupying half the breadth of the tooth; there is not a median ridge. Posterior ridge rises abruptly from the depressed concave portion, extending obliquely from the convoluted anterior margin, gaining in breadth posteriorly and ending in an obtusely rounded posterior margin. Surface coarsely punctate.

This beautiful little species, dedicated to Sir Philip Egerton by his friend Prof. Agassiz, whilst possessing the generic characters of Streblodus, is distinguished from

the species already described by its crown being divided into two principal parts, a broad posterior ridge and anteriorly a wide sulcus or concave depression bounded anteriorly by a well-defined ridge. The intermediate ridge, present in both the species, *S. oblongus* and *S. colei*, in this species is absent.

Formation and locality; Mountain Limestone, Bristol and Hook Point, County Wexford.

Ex coll. Earl of Enniskillen.

Genus.—Deltodus, Agass. MSS.

Pœcilodus—L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., p. 174, indet.
" F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 640.
Deltodus —L. Agassiz,	1859.	MS. Enniskillen Coll.
" Newberry and Worthen,	1866.	"Palæont. Illinois." Vol. II., p. 95.

Teeth, of varied form and size depending on their position in the upper or lower jaw, possessing the following generic characters respectively:—

Upper jaw. "Teeth of medium or large size, thick and strong, triangular in outline, more or less arched, sometimes enrolled in the line extending from the longest and most acute angle to the opposite margin; crown-surface sometimes simply arched, more generally marked by 1–3 prominent ridges, running from the basal margin towards the longest angle. In some species the triturating surface is also undulated by a series of transverse obtuse ridges, parallel with the basal margin, and mostly confined to the basal portion of the tooth. The crown surface is uniformly punctate, the size and form of the pores varying in the different species."—(*Newberry and Worthen.*)

Lower jaw: probably three teeth on each side. Posterior tooth, large, more or less quadrilateral in outline, thick and strong, prominent convexity occupies greater portion of crown surface, depressed on the internal lateral area forming an aliform expansion. Anterior margin curved sigmoidally, laterally straight, converging backwards forming a subtruncate, recurved posterior extremity.

Second or median tooth: much smaller than the first, triangular in form, convoluted posteriorly; convex with a median ridge; anterior margin circular, laterally straight, converging backwards to an obtuse point.

Third or anterior tooth: small, triangular, expanded anteriorly; rapidly contracted backwards, prominent ridge extends across the tooth from front to back with a wide expansion of the coronal surface towards the antero-lateral angle.

In some species the teeth are marked by transverse imbricating folds or ridges, which may extend parallel with the anterior margin, over a part or the whole surface of the tooth.

The palatal teeth included in this genus were originally placed by Prof. Agassiz amongst the genus Pœcilodus as two species *P. sublævis* and *P. parallelus*; they were, however, neither described nor figured. Prof. M'Coy described and figured the specimens as named by Prof. Agassiz in his work on the British Palæozoic Fossils. He considered that the triangularly oblique and aliform

tooth was the terminal posterior one (here described as the tooth of the upper jaw). The wider subquadrilateral palate is taken as the anterior tooth from the same jaw. *Poecilodus parallelus* Ag. is described as a separate species, but Prof. M'Coy remarks that "from the character of its ridging, and from the parts on the inner and outer sides of it, and the general agreement of the margins, &c., I have little doubt that this will ultimately prove to be the middle tooth of the *P. sublævis*" (*Deltodus sublævis*). Since the above was written specimens have been discovered with the teeth of *P. sublævis* and *P. parallelus* cemented together in juxtaposition, and these prove the correctness of the conviction of Prof. M'Coy.

In 1858 whilst Prof. Agassiz was visiting this country he spent some time in re-examination of the limestone palates in the Enniskillen Collection, tabulating the result of his labours with a view to the publication of a memoir on the subject at an early date. His death, unfortunately intervened before the memoir was prepared. It was during this visit that the two genera Cochliodus and Pœcilodus were thoroughly revised and the great accumulation of specimens led Prof. Agassiz to remove some of the species and form new genera for their reception. Amongst the new genera were Psephodus, Streblodus, Deltoptychus, Xystrodus, and Deltodus. Since the institution of these genera, many new species have been added to them from the Limestones of Illinois and other American localities by Messrs. Newberry and Worthen and others.

Deltodus sublævis, Agass. MSS.

(Pl. LII., figs 7–9.)

Pœcilodus	sublævis,	L. Agassiz,	1838.	"Rech. sur les Poiss. Foss.," Vol. III., p. 174, indet.
,,	parallelus,	,,	1838.	,, ,, ,, ,, ,, ,, III., p. 174, ,,
,,	sublævis,	J. E. Portlock,	1843.	"Geol. of Londonderry, &c.," p. 461.
,,	parallelus,	,,	1843.	,, ,, ,, p. 461.
,,	sublævis,	C. G. Giebel,	1848.	"Fauna der Vorwelt.," Vol. I., pt. iii., p. 337.
,,	parallelus,	,,	1848.	,, ,, ,, Vol. I., pt. iii., p. 337.
,,	sublævis,	H. G. Bronn,	1848.	"Nomencl. palæont.," p. 1022.
,,	parallelus,	,,	1848.	,, ,, p. 1022.
,,	sublævis,	,,	1849.	"Enumerator palæont.," p. 647.
,,	paralellus,	,,	1849.	,, ,, p. 647.
,,	sublævis,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
,,	parallelus,	,,	1854.	,, ,, ,, p. 340.
,,	sublævis,	F. J. Pictet	1854.	"Traité de Paléont.," Vol. II, p. 270.
,,	parallelus,	,,	1854.	,, ,, Vol. II., p. 270.
,,	sublævis,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 640, pl. 3 I, figs. 7, 8, 9.
,,	parallelus,	,,	1855.	,, ,, ,, p. 640, pl. 3 I, fig. 6.
Deltodus	sublævis,	L. Agassiz,	1859.	MS. Enniskillen Coll.
,,	,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,,	,,	Enniskillen,	1869.	"Catal. Types Foss. Fishes," p. 4.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devonico Carb.," p. 353.

The teeth comprised in this species vary greatly in form. There is no evidence that there was more than one tooth in each ramus of the upper jaw, whilst in those of the lower one there were two, probably three, to each. The teeth in the upper jaw were more or less triangular in outline, somewhat flattened anteriorly, with a strong ridge extending from the posterior or apical extremity towards the anterior margin. Greatest length 1·4 inches, width across anterior surface ·8 of an inch. A transverse section across the tooth exhibits a sigmoidal curvature along its surface; a strong ridge occupies half the surface nearest to the median line; the remaining portion being depressed and concave. The surface is uniformly punctate and a number of imbrications extend across its surface parallel with the anterior margin. Anterior margin sigmoidally curved, bending with a convex line from the median antero-lateral angle towards the opposite one, which is considerably extended and acutely pointed; median lateral margin slightly convex; opposite or postero-lateral margin for two-thirds its length straight, it then makes a flexure inwards, and with the ridge of the crown forms an enrolled beak-like posterior termination, the latter being thick and tumid. The base appears to conform generally with the crown in outline; it is thin anteriorly and increases in thickness and strength posteriorly. Its structure is open and porous with a coating of enamel on the crown.

Taking the number of upper teeth hitherto found, about one half of them answer to the above description, whilst the remaining half are reversed. They appear to have been connected with each other along the median lateral margin by a ligament or otherwise, one attached to each ramus of the jaw. This is rendered probable from the fact that such an arrangement would fit and correspond with the form of the opposing teeth of the lower jaw; the high convex ridge of the upper tooth would be in contact with the hollow concave portion of the teeth of the lower jaw, whilst the convex part of the lower teeth fitted to the concave of those of the upper series.

Lower jaw: teeth differ considerably from those of upper jaw. The two central teeth were connected by their internal lateral margins over the median line of the lower jaws, the opposite or external lateral margins being connected with one, probably two posterior teeth on each ramus of the jaw. The posterior teeth are quadrilateral, the sides nearly or quite straight, ·6 inch in length, ·8 inch broad in front, and about half that width behind. Crown antero-posteriorly round and convex, laterally depressed and concave from the external margin to one-third the breadth of the crown. Remaining two-thirds constitutes a broad deeply convex ridge extending the whole length of the tooth. Surface enamelled, granulo-punctate, with a number of transverse equidistant sulci, and intermediate ridges extending parallel with the anterior margin; in some teeth they are almost obliterated by attrition presenting a simple smooth

surface. Anterior margin curved sigmoidally, conforming to the shape of the crown, comparatively thin and acuminate, lateral margins straight, forming a slight ridge projecting beyond the edge of the base.

Posteriorly the surface of the crown is convoluted, folding over with a helix-like coil, the lateral margins of which converge until they form an obtusely pointed angle. The base is thick and strong, especially where the ridge of the crown is highest, becoming thinner anteriorly; in structure it is coarser and openly striated.

Connected with the posterior tooth a second one (see Pl. LII., fig. 9), hitherto regarded as a separate species under the name *Pœcilodus parallelus,* has been found, which leaves no room to doubt that it is in its natural position, and from the character of its inside margin leads to the natural inference that a third tooth occupied the front or median portion of the lower jaw. The second tooth is triangular and "narrow, very much inrolled spirally, the curve exceeding a semicircle." Length ·6 inch; anterior breadth ·4 inch, converging backwards to a recurved point. A median ridge, occupying the major portion of the surface of the crown, extends from the anterior margin backwards to the pointed apex; a second ridge is also present forming the lateral margin of the crown, and between this and the median one there is a depression extending between, and parallel with, the two ridges. The surface is more deeply sulcated than that of the first tooth, but this is probably accounted for by the tooth being subjected to a smaller amount of attrition.

Included in the collection are examples of teeth which approach near to an equilateral triangle; they are proportionately much broader across the anterior margin and shorter laterally than the second pair described above; posteriorly they form an acute point slightly recurved, in other respects they are the counterpart of the second tooth and it is probable that they were connected with it, and formed the median tooth on each side the symphysis of the lower jaw.

The more or less pointed posterior apex of the teeth composing this species, and their ever widening anterior margin, together with the parallel sulci and ridges which extend transversely across the surface have very much the appearance that would be presented if they marked lines of additional growth and there can be little doubt that these teeth have increased in size by successive additions to their anterior margin. The general form and character of the teeth are abnormal and have no living representatives at the present time, so that it is extremely difficult either to reconstruct the general form of the mouth or to obtain a correct idea of the zoological position of the fish. Judging, however, from the paucity of its remains, there can be little doubt that it was a cartilaginous one, and from its association with fishes of elasmobranch structure, and animals of marine growth and habits, it may possibly be inferred with safety

that it was an inhabitant of salt water. The rounded form of the teeth, even where most worn only rendered smooth, and never hollowed out as in some other genera, may lead to the inference that the fish was wholly, or in part a vegetable feeder.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen

Deltodus expansus, Davis.

(Pl. LIII , figs. 9, 10, 11.)

Teeth, generally similar in arrangement to the type species, *D. sublævis*. Central pairs of teeth, of upper and lower jaws, are the only ones identified. In each pair they are widely expanded laterally, compared with *D. sublævis*. Teeth of the upper jaw are 1·1 inch in length, and ·8 inch across the anterior margin; posteriorly they are constricted to an acute angle. Crown; a sub-angular ridge extends from posterior angle to the anterior margin, dividing the surface into two unequal parts; the median portion slightly concave, with a marginal ridge extending along the edge to which the opposite tooth was attached—on the opposite side the surface is expanded, and forms a widely concave area with a lateral marginal ridge. The whole coronal surface is punctate. Anterior margin circular, the outer antero-lateral angle very slightly produced, lateral margins straight or very slightly convex, converging posteriorly to a somewhat acute and prominent apex.

Teeth of the lower jaw wider than long, a broad ridge extends antero-posteriorly across the crown ; on the outer side of this ridge the surface is concave, depressed, and widely expanded, terminating in a raised lateral margin, surface pustulate; transverse ridges absent.

This species differs from *D. sublævis* in its more angular form, and its widely expanded concave surface. The posterior prominence is not so recurved and beak-like, and the anterior margin is more rounded ; it lacks the acutely pointed antero-lateral angle, which is one of the characteristics of *D. sublævis.*

Formation and locality : Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Deltodus aliformis, M'Coy.

(Pl. LIII., fig. 12.)

Pœcilodus aliformis—		F. M'Coy,	1848.	"Ann. Nat. Hist.," Sec. Ser., Vol. II., p. 129.
„	„	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 270.
„	„	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
„	„	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 638, pl. 3 G., fig. 10.
„	„	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„	„	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 75.
„	„	J. J. Bigsby,	1878.	"Thesaurus Devon. Carb.," p. 363.

Teeth, "Wing-shaped or contorto-subtrigonal, narrow before, broad and subtruncate behind, inner straight margin thin, higher in the middle than at each end; the surface seeming concave from thence to the external oblique margin, which is abruptly deflected, much thickened, rounded, strongly arched downwards at each end, with a slight sigmoidal curve; this ridge is crossed by seven or eight large obtusely rounded wrinkles, which become obsolete as they approach the thin inner margin—surface finely granuloso-punctate under the lens." (M'Coy).

A single specimen described by Prof. M'Coy is in the Woodwardian Museum, at Cambridge; it is the same which is figured in the British Palæozoic Fossils, Pl. 3 G., fig. 10. So far as I know there is no other specimen of the same species. It bears a considerable generic resemblance to *Deltodus* (formerly Pœcilodus) *sublævis*, though differing considerably in details. It is apparently of the same genus, and I have therefore transferred it from Pœcilodus to Deltodus, retaining Prof. M'Coy's specific name. Its strong sigmoidal contortion and the great size of the transverse waves or wrinkles, distinguish it from *Deltodus sublævis*, Ag.

Formation and locality: Black Upper Limestone of Derbyshire.
Ex. coll. Woodwardian Museum, Cambridge.

Genus.—Deltoptychius, Agass., MSS.

Cochliodus—	L. Agassiz,	1838.	"Poiss. Foss.," Vol. III., p. 174, indet.
Cochliodus—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 621, pl. 3 I., fig. 24.
Deltoptychius—	L. Agassiz,	1859.	"MSS. Enniskillen Coll."

Palatal teeth of medium size, oblong or triangular in outline. Posterior margin widest, diminishes in breadth forwards. Anterior, spirally convoluted. Crown, convex, raised with three more or less prominent ridges which expand radially from the incurved anterior extremity; posterior margin convex, antero-lateral margin inrolled backwards, median margin thick, convoluted backwards. Surface minutely pustulate; where worn it presents a punctate appearance. Base thick and strong, concave.

The teeth comprised in the genus Deltoptychius were originally considered by Prof. Agassiz to be a species of Cochliodus, and were named by him *Cochliodus acutus* ("Poiss. Foss.," Vol. III., p. 174), but were not described. Prof. M'Coy, accepting Agassiz's definition, described and figured the specimens as *C. acutus* ("Brit. Palæoz. Foss.," p. 621, Pl. 3 I., figs. 24, 25, and 26). The two first figures are those of the teeth of the lower jaw (those called posterior teeth); they exhibit very imperfectly the convoluted, almost helicine infolding of the anterior portion of the tooth.

The tooth of the upper jaw (anterior of M'Coy), represents a very small and imperfect specimen. In all the collection which forms the subject of the following

descriptions there is no distinct evidence of there having been more than a single tooth to each ramus of the jaw. It is possible, nevertheless, that, as in the case of Streblodus, there may have been smaller teeth situated in a position anterior to those of the lower jaw, and it may be well to withhold a firm opinion on the subject until further negative or affirmative evidence shall have been adduced from future discoveries.

The genus Deltoptychius differs from Cochliodus in the prominence and individuality of its ridges, especially the median and anterior ones, and the deeply concave sulcus separating them. The median ridge in the former extends much more obliquely across the surface of the crown, causing the posterior margin to assume a broader expansion than in Cochliodus.

Deltoptychius acutus, Agass., MSS.

(Pl. LIII., figs. 13–17,)

Cochliodus acutus—	L. Agassiz,	1838.	"Rech. Poiss. Foss.," Vol. III., p. 174, indet.
,, ,,	J. E. Portlock,	1843.	"Geol. Report of Londonderry, &c.," p. 466.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 336.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 317.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 647.
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 322.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 267.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 621, Pl. 3 I., fig. 24.
Deltoptychius acutus—	L. Agassiz,	1859.	"MSS. Enniskillen Coll."
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
Cochliodus compactus—	R. Owen,	1867.	"Geol. Mag.," Vol. IV., p. 59, Pl. IV., fig. 1.
Deltoptychius acutus—	Enniskillen,	1869.	"Catal. Types Foss. Fishes," p. 4.
Cochliodus acutus —	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., spt., p. 69.
Deltoptychius acutus—	Armstrong, Young, and Robertson,	1876.	"Catal. W. Scot. Foss.," p. 61.
,, ,,	J. J. Bigsby,	1878.	"Thes. Dev. Carb.," p. 353.

Prof. M'Coy describes the teeth as follows—"Posterior tooth, oblong, obliquely attenuated behind at an angle of about 65°; anterior edge sloped backwards and inwards at about 60°; surface with three very strongly marked, oblique ridges, separated by deep concavities; the first ridge most prominent, narrow, acutely angulated, coinciding with the anterior edge, which is very deeply sloped, usually separated from the adjoining concavity by an obscure narrow sulcus; middle ridge much broader and placed rather behind the middle of the tooth, sloping gradually towards the base of the anterior ridge, but abruptly rounded into the deeper and narrower concavity, which separates it from the posterior marginal ridge which is prominent, narrow, and rounded, forming the posterior point of the tooth. Middle tooth unknown. Anterior tooth, small triangular, marked with three narrow prominent, very oblique ridges, the first coinciding with the posterior margin, and

forming an angle of 50° with the outer edge, the anterior part of which forms the third ridge; the secondary ridge is more obtuse than the other two, and a little on the posterior side of the middle, the intervening spaces deep, concave. Entire surface, minutely granulo-punctate, by the extremities of the vascular canals (averaging eight in one line), covered in some places with a very thin layer of ganoine. Average length of posterior tooth one inch two lines, width at anterior margin eight lines, length of anterior tooth seven lines, width of posterior margin six lines."

In the above description Prof. M'Coy, describes each ramus of the jaw as consisting of three teeth and describes two of them, the posterior and anterior ones; the middle tooth being unknown. By a careful comparison of the teeth, which form a very numerous suite, in the Enniskillen Collection, it has been found that they may be naturally and easily divided into four groups, viz., the right and left teeth of the upper jaw (M'Coy's anterior teeth) and the right and left teeth of the lower jaw (called by M'Coy, posterior teeth). The former described by Prof. M'Coy, as seven lines in length, average in the Enniskillen Collection 1·25 inch, and several examples are more than 2 inches in length, and 1·5 inch across the posterior margin; a larger size than is exhibited by the opposing teeth of the lower jaw. The triturating surfaces of the teeth by the arrangement indicated above correspond one to the other; the hollow of the upper tooth corresponding to the projections or ridges of the lower one, and *vice versa;* this is especially the case in some of the larger specimens, whose surface is much worn, and considering that it is quite impossible to ascertain the actual teeth which pertained to any identical fish, the worn surfaces fit very accurately to those of the opposing jaw.

The teeth are strong and thick; in large and well developed specimens the thickness is equal to half the width. Anteriorly, the tooth is comparatively thin, it increases in thickness towards the posterior and median portions and as is the case with other Cochliodonts it is probably in this direction that the tooth has increased in size, the growth being along the posterior edge.

Prof. Owen, in the Geological Magazine (Vol. IV., p. 62, pl. iv., fig. 1), describes a tooth from the Limestone of Yorkshire, at present in the Woodwardian Museum, Cambridge, as *Cochliodus compactus* "the predominance of the middle over the posterior and anterior lobes giving the guiding surface of the tooth a more compact and simple character." It is an example of *Deltoptychius acutus,* Agass., and as the latter name has priority, *C. compactus,* Owen, can only be retained as a synonym.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Deltoptychius gibberulus, Agass. MSS.

(Pl. LIII., figs. 18–19.)

Deltoptychius gibberulus—	L. Agassiz,	1859.	"MSS. Enniskillen Coll."
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
" "	Enniskillen,	1869.	"Catal. Types. Foss. Fishes," p. 4.
" "	J. J. Bigsby,	1878.	"Thes. Dev. Carb." p. 353.

Teeth of lower jaw, more rhomboidal in outline than in *D. acutus,* and ridges less acutely developed. Surface formed of three ridges with intermediate sulci, first ridge corresponding with the antero-lateral or median margin, is obtuse and rounded, descending at an acute angle to the edge of the tooth; middle ridge broad and gibbous occupying a large proportion of the surface of the tooth, and much wider than in *D. acutus;* separated from the anterior ridge by a narrow and not very deep sulcus, which towards the anterior extremity is almost obliterated. The third ridge is imperfectly preserved, but sufficient remains to show that it was broader and more prominent than in *D. acutus;* the sulcus intermediate between this and the median ridge is shallow and wide, quite different from the deep and narrow concavity of *D. acutus.* Length, 1·25 inch, median margin ·7 inch. Teeth of upper jaw, sub-triangular in outline, greatest length 1·0 inch, along the antero-lateral margin breadth, across posterior margin ·7 inch, and of the median edge ·7 inch. The crown is formed of a large median ridge, and two much smaller and less developed ones forming the antero-lateral and posterior margins of the tooth. The median ridge is pointed and narrow anteriorly, gradually expanding posteriorly into a broadly rounded convexity which occupies the greater part of the coronal surface. The depression or sulcus between the median and antero-lateral ridge is somewhat deep anteriorly, widely expanded and shallow towards the posterior margin; postero-lateral ridge slightly prominent, much less so than in *D. acutus;* antero-lateral ridge, angular, small, much inferior to the median one in height, intervening sulcus slight and narrow. This species differs from *Deltoptychius acutus* in the broadly expanded median ridges as compared with the less prominent ones of *D. acutus,* whilst the lateral ridges, acutely prominent in the latter are comparatively small and obtuse in *D. gibberulus.* The posterior margin of the teeth of the upper jaw of *D. acutus* is convex and rounded, extending considerably beyond the antero and postero-lateral angles, whilst in *D. gibberulus* the margin is almost straight.

Formation and locality: Mountain Limestone, Bristol. Hook-point, Ireland.
Ex. coll. Earl of Enniskillen.

Genus.—Sandalodus, N. & W.

Sandalodus—Newberry & Worthen, 1866. "Geol. Surv. Illinois," Vol. II., p. 102.

"Teeth of medium or large size, thick and strong, sub-triangular or club-shaped in outline, with one and sometimes two pointed extremities; generally somewhat twisted, slightly arched longitudinally, strongly so transversely; enamelled surface finely and uniformly punctate; base deeply concave both ways, curves following those of the surface of the crown; towards the narrower end in some species, one or two obtuse ridges running obliquely over the tooth as in Cochliodus."—N. & W.

The above is the description of the teeth of the lower jaw; the following of those of the upper one:—Large, thick, massive, triangular in outline, anterior extremity pointed and convoluted inwards; surface more or less concave, expanded posteriorly and terminating with a broadly rounded posterior margin. External margin prominent, angular, and inrolled. Enamelled surface punctate. Base generally similar in form to the crown. A considerable number of specimens of this genus have been collected at Oreton, in Salop, and from the Black Rock near Bristol. The teeth from both localities are similar, and consist of the two forms described above, and though they have not been found associated together in a natural position, the fact that teeth of so large a size and identical texture are found in two localities similarly associated and other minor considerations, renders it almost certain that they are from the upper and lower jaws respectively of the same species. The specimens figured, though they may not be from the jaws of the same fish, fit each other with tolerable accuracy, the concave surface of the upper jaw corresponding to the convex one of the lower.

The teeth of the upper jaw bear more than a passing resemblance to those of Deltodus, and indicate a very close relationship between the two genera. The teeth of the lower jaw are more like those of the posterior tooth of Streblodus than Cochliodus, as stated by Messrs. Newbury and Worthen. The species now under consideration are devoid of the slightest indication of "obtuse ridges running obliquely over the tooth," they are quite plain and smooth.

The method by which the teeth of this genus have grown is very well shown in the specimens figured. It does not appear probable that there was more than one tooth to each ramus of the jaw. Those of the lower jaw are incurved, and to some extent have enveloped the outer anterior margin of the jaw; from this surface the teeth expand inwards, and are largely developed backwards. The successive increases in the size of the tooth are occasionally indicated, as on the tooth represented by Figure 1, Plate LIV. This is exactly the method by which the teeth of the genera Streblodus and Cochliodus increased in size, but whereas the dentition of those genera is divided into two or three teeth with prominent transverse ridges; in the present one there is only one undivided tooth without ridges.

The teeth of the upper jaw have similarly developed from the outer margin of the tooth : a transverse section of a tooth, (Plate LIV., Figures 3*a*, 4*a*), represents the incurved lateral margin on the outside of the dextral tooth. The growth in this instance very nearly approaches that of the tooth of *Deltodus sublævis,* and serves to show the close connexion that exists between the genera Cochliodus, Streblodus, and Deltodus. The suggestion is also forcibly impressed that the upper teeth of the genera Cochliodus and Streblodus were probably somewhat similar in form to Sandalodus and Deltodus, and though they have not yet been determined, it is not improbable that they may be found amongst some of the teeth now considered either as separate genera or classified with some other one.

Sandalodus morrisii, Davis.
(Pl. LIV., figs. 1–6.)

Deltodus sp. ?—Morris and Roberts, 1862. "Quart. Journ. Geol. Soc.," Vol. XVIII., p. 105. pl. 3, fig. 1, 1a.

Teeth of lower jaw, large and massive, 4·5 inches in length, and 1·75 in breadth near the centre. Crown longitudinally convex, transversely deeply convex, smooth, polished, uniformly and finely punctate, surface evenly rounded, with the exception of one or two flattened areas, apparently worn by attrition. Lateral margins slightly rounded, extremity obtusely pointed. Base ·4 inch thick near the end, thinner in the centre of the tooth, partakes generally of the form of the crown, but is considerably constricted in extent.

Teeth of upper jaw, large in size, thick and strong, triangularly elongated, posteriorly convoluted, length 4·0 inches, breadth anteriorly 1·8 inch. Crown in longitudinal section, the surface is deeply convex, the external lateral margin formed by a prominent ridge, which extends from the anterior apex towards the posterior margin, becoming much expanded and proportionately depressed. The internal lateral surface is more or less expanded and concave. The surface of the crown is uniformly and minutely punctate. Where the surface has not been abrated each minute orifice is surrounded by a raised ring of black enamel, the enamel being continuous from one pore to another, and covering the intermediate space. Posterior margin rounded or circular, considerably worn by attrition; the median lateral margin slightly convex, the opposite margin straight, angular, and convoluted. A transverse fracture shows the tooth to be at least ·4 of an inch thick. The base is thick, strong, and fibrous in structure, full of ramifying dentigerous canals in connexion with the punctate orifices of the surface enamel. The base projects some distance beyond the crown along the posterior surface, and also for a distance of an inch and a half along the inside lateral margin; in other respects it conforms generally to the surface of the crown. The anterior portion of the tooth is thinnest, and its thickness increases backwards in the same ratio that the tooth increases in size. From the rough, porous, incomplete appearance

of the posterior margin it may perhaps be inferred with reasonable probability, that a process of growth increasing the size of the tooth along its broad posterior and inside margin may be indicated; though there are no lines or ridges indicating growth as in *Deltodus sublævis,* this method agrees with the other species in its application. The specimens found at Bristol are smaller than those from Oreton, but there does not appear to be any distinguishing feature which would lead to the supposition that there is any specific difference between them.

Sandalodus morrisii was found associated with several other species of fish-remains in the Mountain Limestone at Oreton, in Shropshire; amongst others were *Orodus ramosus* and species of Helodus, Cochliodus, Cladodus, Psammodus and Ctenacanthus. It is figured without name or description in the "Quar. Journ. Geol. Soc." Vol. XVIII., pl. iii., figs. 2a, 2b, 2c, by Prof. J. Morris, and Mr. Geo. E. Roberts.

The upper teeth of this species bear a superficial resemblance to an American species, *Deltodus grandis,* Newberry and Worthen, from the Keokuk Limestone of Illinois. It may, however, be easily distinguished by its generally rounded and more circular form, and the absence of a deep sulcus extending longitudinally parallel with the lateral ridge; in *D. grandis* the broader end of this sulcus is strongly elevated.

I have taken the liberty of appending the name of Prof. Morris to this species, he having first introduced it to notice in the paper cited above in 1862. Hitherto it is the only described species of this genus from British strata.

Formation and locality: Mountain Limestone, Oreton, Salop; Black Rock, Bristol.
Ex coll. Earl of Enniskillen; Dr. Grenfell, and Bristol Museum.

Genus—Psephodus, Agass., MSS.

Cochliodus—	L. Agassiz,	1838.	"Rech. Poiss. Foss.," Vol. III., p. 174, indet.
Helodus (partim)—	„	1838.	„ „ „ „ III., p. 173.
Psephodus—	„	1859.	"MSS. Enniskillen Coll."
Aspidodus—	Newberry and Worthen,	1866.	"Geol. Surv. Illinois," Vol. II., p. 92.

Palatal teeth varying greatly in size and form; outside sub-rhomboidal inclined to pentagonal or oblong; surface, broadly convex with a decided obliquely diagonal torsion. Diameter varies from 2·1 by 1·5 inches, to others which are ·5 by ·2 inch only. Anterior margin more or less convoluted, comparatively broad; surface expands posteriorly to nearly double the width of the anterior margin. Posterior margin, rotund. Sides, straight where the teeth have been in juxtaposition; margins all vertically plicated. Coronal surface thickly coated with enamel or dentine, porous or pustulate. Base, thick and strong, conforms to surface of crown but is considerably constricted in area.

The teeth included in this genus were originally named by Prof. Agassiz, *Cochliodus magnus* and they have since been figured by Portlock (Geol. Rept. pl. 14a, fig. 4) and described by Prof. M'Coy (Brit. Palæoz. Foss., p. 622). Admiral Jones, to whom ichthyologists are indebted for much research and many valuable suggestions in connection with the fish remains of the Mountain Limestone, indicates a probability that the teeth of *Cochliodus magnus* and *Helodus planus* belonged to the same fish. He does not, however, suggest any possible arrangement of the palates. The inference is very likely correct, and if a tolerably perfect example of the palate should fortunately be discovered, it will probably be found to consist of three teeth of the species hitherto known as *Cochliodus magnus* on each ramus of the jaws, increasing in size backwards, and a number of teeth of *Helodus planus* arranged between the jaws, forming a close pavement-like series also increasing in size backwards.

During the year 1858, Prof. Agassiz removed this group of teeth from the genus Cochliodus and instituted the new genus Psephodus for its accommodation. The so-named types remained in the collection of Lord Enniskillen but like many others were not described.

In the Palæontology of Illinois (Vol. II., p. 92) Messrs. Newberry and Worthen describe and give figures of a number of palates from which they have originated the genus Aspidodus. At the same time they indicate its relationship to the teeth of *Cochliodus magnus*, Ag., and *Helodus planus*, Ag., and suggest the latter should be included in their new genus. There is little doubt that they are generically identical and should be joined together in one genus, but as priority is generally taken as the guide in instances of synonymic nomenclature, it will be evident that Agassiz's genus Psephodus must be retained and the genus Aspidodus, Newberry and Worthen, merged with it.

Psephodus magnus, Agass., MSS.

(Pl. LV., figs. 1–14.)

Cochliodus magnus—L. Agassiz,	1838.	"Rech. sur l. Poiss. Foss." Vol. III., pp. 174, 384 (indet).
Helodus planus, "	1838.	" " " " " III., p. 173.
Cochliodus magnus—J. E. Portlock,	1843.	"Rept. Geol. Londonderry, &c.," p. 466, pl. XIVa, fig. 4.
Helodus planus, "	1843.	" " " " 462.
Cochliodus magnus—C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 336.
Helodus planus, "	1848.	" " " " I., pt. 3, p. 341
Cochliodus magnus—H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 317.
Helodus planus, "	1848.	" " p. 583.
Cochliodus magnus, "	1849.	"Enumerator Palæont.," p. 647.
Helodus planus, "	1849.	" " p. 647.
Cochliodus magnus—J. Morris,	1854.	"Catal. Brit. Foss.," p. 322.
Helodus planus, "	1854.	" " " p. 328.

Cochliodus magnus—F. J. Pictet,		1854.	"Traité de Paléont.," Vol. II., p. 267.
Helodus planus,	,,	1854.	,, ,, ,, ,, II., p. 267.
Cochliodus magnus—F. M'Coy,		1855.	"Brit. Palæoz. Foss.," p. 622.
Helodus planus,	,,	1855.	,, ,, ,, p. 631. pl. 31, figs. 12–15.
Psephodus magnus—L. Agassiz,		1859.	"MSS. Enniskillen, Coll.,"
Cochliodus magnus—Morris & Roberts,		1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
Psephodus magnus,	,, ,,	1862.	,, ,, ,, ,, ,, XVIII., p. 101.
,, ,,	Enniskillen,	1869.	"Catal. Types, Foss. Fishes," p. 7.
Cochliodus magnus—Young & Armstrong,		1871.	"Trans. Geol. Soc. Glasgow," Vol. III., supt. p. 70.
Helodus planus,	,, ,,	1871.	,, ,, ,, ,, ,, III., supt. p. 72.
Cochliodus magnus	Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 61.
Helodus planus,	,,	1876.	,, ,, ,, ,, p. 62.
Psephodus magnus,	,,	1876.	,, ,, ,, ,, p. 63.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb., p. 364.
,, ,,	L. G. de Koninck,	1878.	"Fauna du Calc. Čarb. d. l. Belgique," p. 60, pl. iv., figs. 14–17.

Posterior tooth irregularly pentagonal, or sub-rhomboidal, broadly convex, moderately arched from side to side, and more or less inrolled at the outer or anterior margin; the antero- and postero-lateral margins diverge from the anterior portion of the tooth; the antero-lateral margin straight or slightly concave, forms a sutural edge for the attachment of the median tooth; posterior margin rounded. "Middle tooth obscurely trapezoidal, having a broad, moderately convex inner margin, from whence the surface is uniformly and gently arched towards the opposite very short side, or obtuse slightly inrolled outer margin; anterior and posterior sutural edges diverging obliquely from the short outer margin; posterior one longest. Anterior tooth subtrigonal, obliquely semi-elliptically pointed in front, and with an oblique nearly straight sutural edge, marking the posterior face of the triangle." The edges of the teeth are all more or less vertically crenulated and the surface uniformly punctate.

The Helodus-like teeth occupying the intermediary portion of the palate are "irregularly elongate, oblong with a slight oblique diagonal twist, narrowed, and rotundato-subtruncate at the ends, between which the crown widens; widest nearer to one end than the other; surface flattened obtusely, slightly convex". They are crenulated or plicated along the edges, and the surface is punctate as in the teeth situated on the jaws.

The large number of teeth comprised in this species are only roughly included in the above descriptions. Their forms are very complex and scarcely two are alike. It appears possible, however, to distinguish amongst the larger specimens two distinct sets, which in all probability belonged respectively to the upper and lower jaws. In the one the crown is semi-globose in section from front to back and highly convex laterally; occasionally one or other part of the crown is worn or abraded by attrition to a flat surface (Pl. LV., fig. 10). In the other the teeth are

much flatter and more nearly pentagonal in outline. Their surface is worn into deep hollows seemingly by impact with the rounded teeth of the opposing jaw. In a few cases the thick dentine is completely worn through, exposing the bony structure below. The base in the larger specimens is quite half an inch in thickness. The smaller teeth, of which there are numerous examples, appear to have been attached to the antero-lateral extremity of the larger ones, they are broadest at the posterior sutural margin and gradually diminish in size anteriorly, where they are connected with a third anterior tooth which is trigonal in form, ending in front with an obtusely pointed angular margin (Pl. LV., figs. 1, 2, 3). It is not probable that more than three teeth existed on each side of the jaw and the teeth hitherto known as *Helodus planus*, Ag., occupied the intervening portion of the palate. An example (Pl. LV., fig. 6) shows a Helodoid tooth to have occupied a position in front of the anterior tooth as well as the palatal space behind.

Formation and locality : Mountain Limestone, Armagh : Kendal.

Ex coll. Earl of Enniskillen.

Genus.—Pœcilodus, Agass., MSS.

Palatal teeth, length equal to half the breath ; subtrapezoidal in outline. Crown, surface raised into folds extending radially from the posterior basal extremity ; transverse lines of ridges extend parallel to the posterior margin decreasing in size forwards. Posterior margin sigmoidally sinuous ; postero-lateral margin more or less straight ; antero-lateral margin convex or straight, converging forwards. Anterior margin, narrow, convoluted downwards.

Median tooth narrow, triangular in outline.

The genus Pœcilodus was instituted by Professor Agassiz (Poiss. Foss., Vol. III., p. 174) and included six species, viz., *P. jonesii* and *P. transversus*, *P. angustus* and *P. obliquus*, *P. sublævis* and *P. parallelus*, of these more recent discoveries have proved the two latter species to be teeth from the jaw of the same fish and that they differ in character and form from the typical *P. jonesii* so completely, that in 1858 Professor Agassiz removed them from the genus Pœcilodus and made them the type of a new genus which he named Deltodus : *P. parallelus*, being the median tooth of *P. sublævis*. The two species *P. jonesii* and *P. transversus*, were also proved to belong to the same fish and the latter has been merged into the former.

Professor M'Coy (Brit. Palæoz. Foss., p. 638), described the genus Pœcilodus and in addition to the Agassizian species *P. jonesii* (with *P. transversus*), *P. obliquus*, *P. parallelus* and *P. sublævis* described two new species, *P. aliformis* and *P. foveolatus*. The last, from the Carboniferous Limestone of Derbyshire, appears to possess the characters of the genus whilst *P. aliformis* is without doubt a Deltodus and must be relegated to that genus. The description of the genus as given by Professor M'Coy is in consequence of the separation of the teeth to form the genus Deltodus, inappropriate and insufficient ; the one above is therefore substituted.

Pœcilodus jonesii, Agass., MSS.

(Pl. LIII., figs. 20–23.)

Pœcilodus	jonesii—	L. Agassiz,	1838.	"Rech. Poiss. Foss.," Vol. III., p. 174 (indet).
„	transversus,	„	1838.	„ „ „ Vol. III., p. 174 (indet).
„	jonesii—	J. E. Portlock,	1843.	"Rept. Geol., Londonderry, &c.," p. 468, pl. 14a, fig. 6.
„	transversus,	„	1843.	„ „ „ p. 468, pl. 14a, fig. 7.
„	jonesii—	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 337.
„	transversus,	„	1848.	„ „ „ Vol. I., pt. 3, p. 337.
„	jonesii—	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 1022.
„	transversus,	„	1848.	„ „ p. 1022.
„	jonesii,	„	1849.	"Enumerator Palæont.," p. 647.
„	transversus,	„	1849.	„ „ p. 647.
„	jonesii—	J. Morris,	1854.	"Catal. Brit. Foss.," p. 340.
„	transversus,	„	1854.	„ „ „ p. 340.
„	jonesii—	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 270.
„	transversus,	„	1854.	„ „ „ Vol. II., p. 270.
„	jonesii—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 639.
„	jonesii—	L. Agassiz,	1859.	"MSS. Enniskillen Coll."
„	„	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
„	„	Enniskillen,	1869.	"Catal. Types Foss. Fishes," p. 7.
„	„	Armstrong, Young and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 62.
„	„	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 363.

Two, probably three teeth were attached to each ramus of the jaw. Posterior tooth thick and strong, obliquely elliptico-trapezoidal in outline; average breadth ·7 inch, length ·35 inch. Coronal surface tumid, convex somewhat flattened towards the antero-lateral margin, moderately convoluted anteriorly; one deep oblique concavity, about one-third the breadth from the anterior margin, divides the surface into two large oblique unequal lobes, extending radially from the convoluted anterior margin; the first lobe slopes gradually so as to form a prominent anterior articular margin; the second or posterior lobe, obtusely rounded, extends parallel with the postero-lateral margin; a number of transverse, strongly marked, projecting ridges extend across the surface, roughly parallel with the posterior margin, decreasing in size forwards, they are separated by deep hollows. The surface is coated with enamel, finely and evenly punctate where unworn, where the surface has been worn, sections of the punctures are exposed. Posterior margin broad, sinuous with a bold convexity conforming to the posterior lobe of the crown; antero-lateral margin straight; postero-lateral margin convex, forming with the anterior one a more or less acute angle, and converging backwards to the comparatively narrow anterior margin which is convoluted inwards. Basal portion conforms generally to the surface.

The anterior or median tooth, named by Prof. Agassiz *Pœcilodus transversus,* was attached to the one described along its antero-lateral margin. Its form is triangular, length, ·45 inch; breadth, ·3 inch across the posterior extremity,

diminishing gradually forwards and ending in an obtuse point. The crown is convex, anteriorly convoluted, a central ridge extends from front to back of the tooth from which the surface slopes on each side, terminating in a slightly raised lateral margin. There are about eight transverse, wide, large, and rounded folds or wrinkles. The whole surface is enamelled and punctured. Posterior margin convex, depressed. Lateral margins straight or slightly convex, anterior ones incurved, pointed.

An example in the Enniskillen collection shows the tooth, *P. transversus*, Ag., in juxtaposition with the anterior lateral margin of the tooth of *P. jonesii*, Ag. It occupies an exactly corresponding position to the second tooth of Deltodus, and in some respects bears a resemblance to that tooth.

A comparison of the above description and the figures (Pl. LIII., figs. 20–23), with those given by Portlock in the Geological Report referred to, show that the two specimens figured by Portlock are both included in the species *P. jonesii* as originally named by Agassiz, and that Agassiz's species *P. transversus* was not known to Portlock, his definition of the difference between the two being, that in the latter "the folds are continued more across the tooth, are less twisted, and not so strong." The description given by Prof. M'Coy of *Pœcilodus jonesii* (+ *P. transversus*) is evidently founded on that of Portlock; the specimens are not figured, but a reference to those in the Geological Report is given; there is no allusion to the median teeth, smaller, narrow, and more triangular in form, which Prof. Agassiz named *P. transversus*, and M'Coy appears also to have accepted the slightly raised forms of the original *P. jonesii* as the *P. transversus*, Ag. An examination of the type specimens named by Prof. Agassiz in the Enniskillen collection proves both authors to have been in error.

Formation and locality: Carboniferous Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Pœcilodus obliquus, Agass., MSS.

(Pl. LIII., fig. 24.)

Pœcilodus obliquus—	L. Agassiz,	1838.	"Rech. sur les Poiss. Foss.," Vol. III., p. 174, indet.
" "	J. E. Portlock,	1843.	"Rept. on Geol. Londonderry," p. 461.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 337.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 1022.
" "	H. G. Bronn,	1849.	"Enumerator Palæont.," p. 647.
" "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
" "	J. F. Pictet,	1854.	"Traité de Paléont., Vol. II., p. 270.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 640, pl. 3 I., fig. 5.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	Young and Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., supt. p. 75.
" "	Armstrong, Young, and Robertson,	1876.	"Cat. West Scot. Fossils," p. 62.
"	J. J. Bigsby,	1878.	"Thesaurus. Devonico-Carb.," p. 363.

Teeth, "Terminal posterior tooth sub-cylindrical, obliquely attenuated semi-elliptically at the posterior end, abruptly truncated at an angle of 80° in front, strongly convoluted, with three very strongly-marked, very prominent, nearly equidistant ridges; the lateral ones formed by the thickened reflexed margins of the anterior and posterior edges; the middle one thicker than the others, and slightly more prominent, bounded on each side by a very broad, deep concavity; the concavities are crossed by strong, subequal, slightly irregular longitudinal wrinkles, separated by deep sulci, which only indent the oblique transverse ridges of the convoluted outer portion; the whole surface strongly granulo-punctate."—(*M'Coy.*)

The length of the specimen figured is ·75 of an inch across the lateral diameter and ·4 of an inch antero-posteriorly. It differs from *P. jonesii,* Ag. in several particulars; the postero-lateral angle is less prominent, whilst the radiating ridges on the surface are much more so, especially the two lateral ones. The posterior half of the tooth in *P. jonesii* is large compared with the remainder, whilst in *P. obliquus* it is smaller and hollowed by the deep concavity between the postero-lateral and median ridges. The inside margin is much more inrolled in *P. obliquus* than in *P. jonesii,* Ag. It has been hinted that some relationship may be found to exist between the Sirenoid Ganoids and the Cochliodonts; should such be the case, it will probably be found that the teeth of this species will approach as near as any to connect the two forms together.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Pœcilodus corrugatus, Davis.
(Pl. LIII., fig. 25).

Teeth, probably anterior, sub-triangular, ·45 of an inch long, and ·3 of an inch in breadth. Lateral margin slightly curved, gradually approaching and meeting posteriorly, forming a slightly inrolled point. Anterior margin circular, depressed. The surface of the crown is slightly convoluted antero-posteriorly, and in the opposite direction convex. Parallel with the anterior margin four wide, obtusely-prominent ridges occupy the central portion with deep intermediate sulci—the ridges terminate before reaching the lateral margins. Attached to the tooth is a portion of a second, probably the larger posterior tooth. The surface is uniformly punctate.

This example, from the Upper Limestone beds of Wensleydale, is similar in form to the anterior tooth *P. jonesii,* Ag. It differs in being rather flatter, and in the surface arrangement. The crown of *P. jonesii* is raised medially in the form of a ridge sloping to each side, with about eight transverse folds. In the present instance four prominent transverse ridges occupy the surface with a special median one.

Formation and locality: Upper Limestone, Wensleydale.
Ex. coll. W. Horne, Esq., Leyburn.

Pœcilodus foveolatus, M'Coy.

(Pl. LIII., fig. 26.)

Pœcilodus foveolatus—	F. M'Coy,	1848.	"Ann. Nat. His.," Sec. Ser., Vol. II., p. 129.
" "	F. J. Pictet,	1854.	"Traité de Palæont.," Vol. II., p. 270.
" "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 639., pl. 3 G., fig. 11.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	J. J. Bigsby,	1878.	"Thesaurus Dev. Carb.," p. 363.

Teeth, "Longitudinally clavate, depressed, nearly three times longer than wide; terminal end narrow, subtruncate; surface obliquely crossed by nine or ten thick, flat, imbricating ridges, varying from one line to half a line wide; they run nearly straight, but each has got an abrupt, angular bend about the middle which makes the posterior half of each edge seem about half a line further out than the anterior half—each imbrication has one, or rarely two rows of large, equidistant puncta, or small pits."

This species is founded on a fragment of a tooth, which still remains unique; it is in the Woodwardian Museum, Cambridge. It is about 1·2 inch in length. Its narrow, elongate form and more numerous, flat, imbricating ridges, the row of notch-like curves, one on the edge of each, and the regular rows of puncta, distinguish this species from *P. jonesii*, Ag.

Formation and locality: Mountain Limestone, Derbyshire.
Ex. coll. Woodwardian Museum, Cambridge.

Pœcilodus gibbosus, Davis.

(Pl. LIII., figs. 27, 27a.)

Posterior teeth, probably of lower jaw, sub-pentagonal in outline, breadth ·6 inch, length slightly less. Crown antero-posteriorly deeply convex, and inrolled posteriorly; surface almost equally divided into two parts. Extending from the antero-lateral margin, which is slightly raised, one half the surface is formed by a wide and deep depression, transversely straight and smooth, longitudinally convex, and in front its area much constricted. The latero-posterior half is occupied by a bold gibbous ridge, posteriorly broad, converging and profoundly convoluted posteriorly; its surface is traversed by a considerable number of segment-like transverse sulci which, however, do not extend to the depression of the surface on either side; the latero-posterior margin is slightly raised in the form of a ridge, between it and the median one there is a narrow groove-like depression. Coronal surface enamelled, and punctate. The puncta on the median ridge are larger and more deeply impressed than on the remaining portions of the surface. Posterior margin sinuous, deeply concave where the depressed surface of the crown impinges.

Laterally the margins are nearly straight—the median one converging obliquely towards the posterior margin, which is comparatively narrow and convoluted inwards. Base not well defined.

This species is defined by well-marked differences from *Pœcilodus jonesii* described above, and *P. obliquus*, M'Coy (Brit. Palæoz. Foss., p. 640, pl. 3 I., fig. 5). The latter is characterized by three strongly convoluted, very prominent, nearly equidistant ridges, with intermediate concavities, the latter crossed by irregular transverse wrinkles, which do not generally extend over the surface of the ridges. *P. jonesii* has two sub-parallel ridges, with one deep intermediate depression, and the whole surface is divided by transverse wrinkles or folds. The species described above has only one important median ridge, larger and broader, in proportion to the size of the tooth, than those of either *P. jonesii* or *P. obliquus*, and the transverse folds extend only over the ridge, and do not traverse the depressed portions of the surface. In *P. gibbosus* the depressed postero-lateral portion is much constricted in area between the anterior and posterior margins—a character which does not obtain in the others.

Formation and locality : Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Genus.—Tomodus, Agass. (MSS.)

Palatal teeth, large, thick, massive, triangular or sub-rhomboidal in outline, convolute. Crown, surface antero-posteriorly semi-rotund, laterally convex, thickly coated with enamel or dentine, punctate. Anteriorly more or less pointed, laterally diverging and forming a broad posterior margin. Base, thick, osseous.

This genus differs from all the other Cochliodont teeth in its thick massive and triangular characters. The postero-lateral margin has evidently been connected with a second tooth or has formed the median line over the jaw, in which case there would probably be only two teeth to each jaw, one on each ramus. The latero-posterior margin is thinner and does not present the appearance of having been attached to another tooth.

Tomodus convexus, Agass. (MSS.)

(Pl. LV., figs. 15–18.)

Tomodus	convexus —	L. Agassiz,	1859.	"MSS. Enniskillen Coll."
,,	,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc." Vol. XVIII., p. 101.
Cochliodus	,,	R. Owen,	1867.	"Geol. Mag." Vol. IV., p. 62, pl. 4, figs. 2–5.
Tomodus	,,	Enniskillen,	1869.	"Catal. Types Foss. Fishes," p. 8.
,,	,,	Armstrong, Young and Robertson,	1876.	"Catal. W. Scot. Foss." p. 63.
		J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb," p. 365.

Palatal teeth of two sizes with distinctive characters. *Larger teeth* triangular, length antero-lateral margin 1·25 inch; postero-lateral margin 1·5 inch, and posterior margin 1·1 inch. Crown, antero-posteriorly deeply convex or semi-globose; laterally convex, even and smooth except where a sulcus extends across the postero-lateral angle of the tooth; thickly enamelled and minutely and closely punctate. Anteriorly the tooth is pointed and convoluted, the lateral margins diverge posteriorly; posterior margin straight or slightly convex; postero-lateral angle produced with a somewhat sinuous flexure. Base ·3 inch thick in centre, thins out slightly towards both the anterior and posterior margins. *Smaller teeth,* oblong or sub-rhomboidal in outline. The surface is laterally concave, the margins being raised and forming a ridge along each side.

The specimen from the Carboniferous limestone of Bristol referred to by Prof. Owen (Geol. Mag. Vol. IV., p. 62), as *Tomodus convexus,* Ag., which forms part of the collection at the Woodwardian Museum, Cambridge, presents every appearance of being, so far as the teeth are concerned, a defective and much broken specimen of *Cochliodus contortus,* Ag.; as remarked by Prof. Owen it is the most completely preserved specimen of a mandible of a Cochliodont known. It will be treated with greater detail when speaking of Cochliodus in this memoir.

Formation and locality: Mountain Limestone, Bristol.

Ex coll. Earl of Enniskillen.

Genus.—Xystrodus, Agass., MSS.

Syn. Cochliodus (pars.)—Agassiz,	1838.	"Rech. Poiss. Foss.,"	Vol. III., p. 174.
„ Pœcilodus „ „	1838.	„ „ „	Vol. III., p. 174.

Palatal teeth more or less triangular in outline, medium or small size, slightly convoluted and acutely pointed anteriorly: antero-lateral margin forms a convex articulating ridge raised higher than the general surface of the crown, the remainder of which is depressed and concave, expanding in breadth posteriorly. Posterior margin sigmoidally convex forming an acute angle with the postero-lateral margin. Surface enamelled, punctate or pustulate—the puncta sometimes arranged so as to fall into regular lines. Base thick and strong.

Xystrodus striatus, Agass., MSS.

(Pl. LIV., figs. 7, 8, 9, 10.)

Cochliodus	striatus—L. Agassiz,		1838.	"Rech. sur les Poiss. Foss.," Vol. III., p. 174.
,,	,,	J. E. Portlock,	1843.	"Rept. Geol. Londonderry, &c.," p. 461.
,,	,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol I., pt. 3, p. 336.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 317.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 647.
,,	,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 322.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont., Vol. II., p. 267.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 624, pl. 3 I, fig. 27.
Xystrodus	striatus—L. Agassiz,		1859.	"MSS. Enniskillen Collection.
,,	,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,,	,,	Enniskillen,	1869.	"Cat. Types Foss. Fishes," p. 9.
,,	,,	Armstrong, Young, & Robertson.	1876.	"Cat. W. Scot. Foss.," 63.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 367.

"Terminal tooth aliform, triangular, very much broader than long; long articular margin forming an angle of about 35° with the outer edge; along this articular margin is the most prominent part of the surface, forming an obtusely rounded, slightly sigmoid ridge; the remainder of the surface being flattened and extending with a slight concavity to the terminal point, which is nearly rectangular and obtuse. Surface with a fine sharp, granulo-punctation having the usual quincuncial arrangement on the long obtuse convexity of the articular ridge, and on the opposite, flattened, terminal angle; but on all the intermediate portion the punctæ fall into regular, slightly flexuous lines, extending longitudinally nearly at right angles to the articular side; about twelve of the lines of punctures in the space of one line."—(*M'Coy.*)

The number of teeth comprised in the above description by Prof. M'Coy has been greatly amplified since he penned the description, and as a result, a comparison of the teeth in Lord Enniskillen's collection proves either that there are two or three species, or that some of the teeth are from the upper, and others of different form from the lower jaws. Prof. Agassiz regarded them as different species, and, there being not the least evidence to the contrary, they will be regarded as separate species at present. The *Xystrodus striatus* (*Cochliodus striatus,* M'Coy) consists of teeth, as stated in the description above, whose surface punctation falls into lines roughly parallel with the posterior margin of the tooth. The teeth are somewhat different in form to those described by M'Coy, an average specimen being ·6 inch along the raised articular margin, and an equal length across the posterior face, whilst the longest side is ·9 inch in length. The anterior margin is considerably inrolled and in this bears some resemblance to the upper tooth of *Deltodus sublævis,* as well as in its apparent method of growth. The

articular margin is very considerably raised above the remaining portion of the crown. The base is thick and conforms generally to the form of the superior surface. About one-half the number of teeth are the reverse of the others and as in Cochliodonts generally, they appear to have been implanted on the opposite rami of the jaws to form palates suited to crush the shells of molluscs or other hard covering of the animals on which they fed.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Xystrodus angustus, Agass., MSS.

(Pl. LV., figs. 19, 20, 21.)

Pœcilodus angustus—	L. Agassiz,	1838.	"Rech. Poiss. Foss.," Vol. III., p. 174, indet.
" "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3. p. 337.
" "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 1022.
" "	H. G. Bronn,	1849.	"Enumerator, Palæont.," p. 647.
" "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
" "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 270.
Xystrodus angustus—	L. Agassiz,	1859.	"MSS. Enniskillen, Coll.,"
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	Enniskillen,	1869.	"Cat. Types Foss. Fishes," p. 9.
Pœcilodus angustus	Armstrong, Young, and Robertson,	1876.	"Cat. West. Scot. Foss.," p. 62.
Xystrodus angustus—	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 367.

Teeth, triangular, cuniform, length ·9 inch, breadth ·35 inch across the posterior margin which is widest, the two sides converge anteriorly to an acutely-pointed, recurved apex. The articular margin is prominent, rounded, and has a curvature from front to back of considerable convexity; the postero-lateral surface of the crown is depressed, slightly concave, and terminates in a slight ridge forming the postero-lateral margin; the latter is straight and anteriorly curved downwards, posterior margin slightly sigmoidal, crown surface is similarly punctated to that of the previous species, though the arrangement in lines is not so clearly shown. Base, thin compared with that of *X. striatus.*

It is possible this species may be the teeth of the upper jaw of *X. striatus,* both are found in the same beds at Armagh, but until some evidence that such was the relation they held is forthcoming, it may be better to regard them provisionally as separate species.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Xystrodus egertoni, Davis.

(Pl. LV., figs. 22, 23, 23a.)

Palatal teeth more or less rhomboidal and angular in outline, 1·1 inch in length, ·4 inch in breadth towards the posterior portion. Anteriorly the teeth are slightly convoluted with a broad termination. The articular margin is thick, prominent, and elevated above the remainder of the crown, the remaining portion of the crown is flat with a very slight concavity, posterior portion of surface much depressed; posterior margin forms an oblique angle with the margin of the articulating ridge. Surface, closely covered with raised pustules, occasionally exhibiting a slight tendency to arrangement in rows, the anterior part of the crown where most worn exhibits a punctate surface as though the pustulated surface had been ground down and a section of the dentigerous tubes exposed. Base very thick.

This species is at once distinguished from those collected at Armagh by the angularity of its proportions and the very slight concavity of its coronal surface. I have indited it to the memory of the late Sir P. Egerton, whose researches in fossil ichthyology will ever serve as a fitting monument to his learning and a model on which to base future investigations.

Formation and locality: Mountain Limestone, Bristol.
Ex coll. Earl of Enniskillen.

Xystrodus pulchellus, Davis.

(Pl. LV., figs. 24, 24a.)

Teeth, small, triangular, length ·3 inch, anteriorly pointed, expanding posteriorly to ·15 of an inch. Surface of crown, concave, rising laterally to form a strong rounded ridge on one margin whilst the opposite one is depressed towards the anterior extremity, but is raised slightly towards the posterior surface. Base hidden. Coronal surface, beautifully marked by a series of transverse ridges parallel to each other extending over the raised lateral ridge and disappearing as they descend to the concave surface, which is smooth. On the opposite margin there is a row of minute denticulations. The whole is uniformly and minutely punctate.

This interesting little species is found in the limestone of Wensleydale, and appears to be quite distinct from the species found at Bristol and Armagh.

Formation and locality: Carboniferous Limestone, Wensleydale.
Ex coll. Reed Collection, York Museum.

Genus—Helodus, Agassiz.

"Sous cette denomination je comprends toutes les dents de Psammodus, dont la surface est parfaitement lisse et le centre plus ou moins renflé en forme de cône obtus. Ces dents sont tantôt allongées et arrondies avec un seul renflement au milieu, tantôt elles présentent une sèrie de cônes obtus, dont celui du milieu est plus élevé, tandis que ceux des côtés vont en diminuant de grandeur, tantôt en fin un simple cône plus ou moins saillant. Toutes les espèces connus ont été trouvées dans les terrains houillers."—(*Agassiz*, "Poiss. Foss.," t. iii., p. 104.)

Prof. Agassiz originally figured the species of the genus Helodus as belonging to the genus Psammodus. The latter embraced all those teeth whose crown was composed of minute vertical tubes, and whose general structure bore a close relationship to that of the Cestraciontes. The surface of the tooth was more or less smooth, but punctate by the open ends of the pores of the crown, without corrugations or striations, unreticulated and devoid of either crests or longitudinal and transverse prominences. The discovery of an increased number of specimens and the great variety of teeth included in the above definition led Prof. Agassiz to divide the genus Psammodus into several others. They were as follows :—

I. Helodus.
II. Chomatodus.
III. Psammodus.
IV. Cochliodus.
V. Strophodus.

During the Geological Survey of Illinois, a number of new species of Helodi were discovered, and amongst them some specimens which exhibited a close relationship between teeth of Helodus and Cochliodus. The specimens are described in the "Palæontology of Illinois," Vol. II., pp. 88–91, and consisted of the upper and lower teeth of a large species of Cochliodus and a number of teeth of Helodus ; in addition, the jaws are also preserved to some extent. The discovery of any semblance of jaws with the teeth attached is an occurrence of such importance that I venture, though rather lengthy, to give Mr. Worthen's description in his own words. "Fragments only of the jaws are visible on the specimens contained in the collection and such as are quite insufficient for determining their form : they are now thin and flattened and much distorted, showing they had little firmness or rigidity, and were, doubtless, for the most part, cartilaginous, though it is possible in part ossified. They do not show a true bony structure, but exhibit on fracture a fine granular composition, such as we have before seen accompanying the more distinctly bony portions of the remains of cartilaginous fishes, indicating, perhaps, a cartilage through which were disseminated innumerable granules of ossific matter.

"The group of teeth impacted together includes at least four distinct and different forms, of which the surface markings, microscopic structure, colour, &c., are precisely the same throughout. These are, 1st. Large, strongly enrolled teeth,

marked with two strong, revolving ridges, separated by a deep furrow, which correspond to the larger of the two teeth of either ramus of the jaw, figured by Prof. Agassiz ('Poiss. Foss. Atlas,' Vol. III., tab. 19, fig. 14), constituting the type of the genus Cochliodus, and the tooth described by Prof. M'Coy under the name of *C. acutus*, Ag. ('Brit. Palæoz. Foss.,' p. 621, Pl. 3 I., figs. 24, 25). The differences between these teeth and ours being only of a specific character. 2nd. A narrow tooth equally convoluted, and having a wedge-shaped outline when seen from above, perhaps corresponding to the anterior pair in Agassiz's figure. This tooth has a single narrow and low revolving ridge, with numerous obscure plications. 3rd. Teeth nearly as long as both the preceding. These teeth are somewhat unlike any hitherto attributed to Cochliodus, and probably belonged to the opposite jaw from that which bore those before mentioned; matching into those when in use. If the teeth described by Agassiz and M'Coy are, as supposed, from the lower jaw, these are from the upper. 4th. Transversely elongated teeth of smaller size, in diminishing series of size, joined by their longer sides, and in some cases retaining their relative positions. These teeth have a more or less distinctly marked prominence or cone upon the crown, and an oblique and flattened root often as high as the crown. Considered by themselves, they would constitute one or more typical species of Helodus.

"They formed several rows, as is indicated by the differences which they present. . . . . The enamelled surface of all these teeth, large and small, has a relatively coarse porosity, precisely the same in all, and it is impossible to resist the conclusion that they all formed parts of the varied dentition of a single fish. As they are now thrown into a confused heap we can only conjecture what the relative position of each form was. It seems probable, however, that the smaller conical teeth (Helodi) formed several series intermediate between the larger and broader ones, upon the symphysis of the jaw. In the living Cestracion we find a precisely similar arrangement. The rami of the jaws are covered with a series of broad, flattened plates, fitted for crushing only, while the mesial portion of each jaw is occupied by numerous rows of small pointed teeth, diminishing in size from front to rear." Whether the median teeth in the fossil Helodus (Cochliodus) were on a single row or were common to both, Mr. Worthen was unable to determine. The specimens were named *Helodus* (*Cochliodus*) *nobilis*, (N. and W.)

If the observations recorded above are correct, and there appears little doubt that they are, the teeth, hitherto considered as distinct genera, are proved to belong to fishes which had a somewhat complicated dentition, and a thorough revision of the whole of the palatal forms of teeth may eventually be necessary. At present, however, the grounds are so slight on which to raise such a fabric that it is impossible to more than hint at such a result, and to hope that ere long fresh discoveries may serve to elucidate the true organization of the fishes that gave origin to the fragmentary remains, which are all we now possess. In the fossil Helodi, found in the Carboniferous rocks in Britain, there is little evidence to show either

the arrangement of the teeth, or whether they formed only a part of a larger series. As almost always happens with the remains of the Elasmobranch fishes, the teeth become detached and separated during the period of their decomposition, and it is almost impossible to correctly infer any relation of one to another when found fossil, under such circumstances.

Of the Helodi already described it is probable that several species, such as *H. turgidus,* were the median teeth of Cochliodus. This will also apply to most of the America specimens. A second type, of which *H. planus* may be taken as an example, has been proved to belong to a distinct genus of fish, and there is no doubt so far as *H. planus* is concerned that it is the inside tooth of *Psephodus magnus.* Capt. T. Jones, in a letter to Portlock, published in the Geological Report of Londonderry, &c., p. 462 (1843), was the first to point out the relationship of *H. planus* to *Cochliodus* (now *Psephodus*) *magnus.* He considered that the one passed into the other. Specimens in the Enniskillen collection show that the two teeth were attached to each other in the same jaw.

It does not appear probable that any of the teeth of Helodus were associated with those of Psammodus, or that the former stands in the relation of a subgenus of the latter, as indicated by M'Coy. There is no evidence of such near relationship, and the general similarity of the porous surface of the teeth relied on by M'Coy, would indicate a relationship with several other genera, quite as reasonably as with that of Psammodus.

Helodus crassus, Davis.

(Pl. LIX., figs. 1, 2.)

Psammodus cinctus (pars) —	L. Agassiz,	1833.	"Rech. Poiss. Foss.," Vol. III., pl. xv., fig. 13–21.
" " "	P. G. Egerton,	1837.	"Cat. Foss. Fishes."
Chomatodus " "	L. Agassiz,	1838.	"Rech. Poiss. Foss.," Vol. III., p. 107.
" " "	J. E. Portlock,	1843.	"Geol. Londonderry," p. 467, pl. xiv.a, fig. 9.
" " "	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 341.
" " "	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 292.
" " "	"	1849.	"Enumerator Palæont.," p. 647.
" " "	J. Morris,	1854.	"Cat. Brit. Foss.," p. 321.
" " "	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 266.
" (Helodus), "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 617.
" " "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 99.
" " "	Enniskillen,	1869.	"Cat. Types Foss. Fish.," p. 4.
" " "	Young and Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 69.
" " "	Armstrong, Young, and Robertson,	1876.	"Cat. W. Scot. Foss.," p. 60.
" " "	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 349.
" " "	L. G. de Koninck,	1878.	"Fauna du Calc. Carb. de la Belgique," p. 46, pl. iv., fig. 3, pl. vi., figs. 1-5.

Teeth, large, laterally elongate; outline irregular, length about double the width, broadest in middle, tapering slightly and unevenly towards each lateral extremity: length 1·2 inch; height of central cone ·45 inch; breadth ·6 inch, diminishing at one lateral extremity to three-quarters, and at the other to half, the greatest breadth; the broader lateral extremity may be either to the right or left of the central cone. Crown: central cone moderately elevated, laterally broad, obtusely pointed: transversely somewhat beaklike, a ridge extends from centre of the cone down each side, it is sinuous and slightly produced to form two or three small minor cones, towards each lateral extremity. Posterior face, depressed from the ridge of the crown to its posterior margin forming a deep concavity; anterior surface, convex; coronal surface, coated with thick, dark, beautifully polished enamel, generally perfectly smooth, but in a few specimens covered with projecting pustulate dots. Posterior ridge separating the crown from the base, broadly expanded, margin concave. Anterior ridge, sinuously convex, broadly expanded. Occasionally four or five concentric plicæ extend along the anterior and posterior ridges, but in the majority of specimens they are not present. Base: ·3 of an inch in depth; laterally, equally extended with the crown, descending obliquely from the posterior portion of the tooth, strong, fibrous in structure.

Helodus tenuis, Davis.

(Pl. LIX., figs. 3, 4.)

Chomatodus cinctus, Ag., pars.

Teeth, long, transverse section laterally much elongated, narrow, elliptical, pointed at each extremity. Length to 1·0 to 1·2 inch, breadth, ·3 to ·4 inch, height of central cone ·35 of an inch. Crown: central cone, elevated, more or less sharply pointed and thin; anterior and posterior faces form a ridge at an acute angle extending from the summit of the cone laterally in each direction and terminating in an acute point. Ridge sometimes straight, in others sinuous; free from minor cones. Anterior surface, convex. Posterior surface, deeply concave, summit of cone recurved. Coronal surface, enamelled; summit of ridge smooth, probably with attrition during mastication, sides of ridge either coarsely punctate or pustulate. Posteriorly a ridge separates the crown from the base, anteriorly the surface of the crown is continued down into the base; there are no concentric folds. Base, ·25 inch in depth, slightly produced anteriorly, rather more widely expanded than the crown, strong and fibrous.

This tooth is easily distinguished from the species last described by its generally more attenuated form and the acuteness of the coronal ridge, extending along the centre of the tooth and its somewhat recurved apex.

This species was included by Professor Agassiz in the genus Chomatodus, but the characteristic on which he lays greatest emphasis, the concentric folds near the base of the tooth, are absent.

Helodus clavatus, Davis.

(Pl. LIX., figs. 5, 6.)

Teeth, long, club-shaped, sinuous in outline, broadly expanded at one end, tapering to a fine point at the other. Length 1·2 inch, breadth ·35 inch, height of crown equal to the breadth. Crown, highest point occupies a position about one-third the length from one of the lateral extremities: the summit forms a longitudinal ridge, extending with a more or less sinuous convexity along the tooth, transversely acuminate, the anterior and posterior surfaces expanding towards the base. From the summit the ridge descends rapidly on the one side, ending in a slightly-expanded obliquely-obtuse angle: on the other the descent is gentler forming an elongated lateral prolongation, triangular in section, and terminating in an acute point. Coronal surface, enamelled, punctate, or pustulate, on different specimens; ridge of crown, worn and smooth; base, large and deep, not well preserved. There is no evidence of concentric or other plicæ. Examples occur of what appears to be a variety of this species. They have a general resemblance in contour and outline, broadly expanded near one extremity, the other tapering and elongate, but in place of being raised to form a transversely acute cone, the crown is expanded and broad, forming a comparatively depressed convex surface, the anterior and posterior margins presenting a lenticular outline. Base not exposed. The coronal surface, as in the specimens already described, is in some instances covered with small pittings, whilst in others, it is raised into small pustulate dots. The large extremity is either to the right or left of the centre, showing in all probability that the teeth have been arranged in at least two parallel rows.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Helodus acutus, Davis.

(Pl. LIX., fig. 7.)

Teeth, small, median cone large, equal in height to the length of the tooth, which is ·4 of an inch. Crown consists of a central cone, with a recurved lateral and posterior basal margin. Central cone, obtusely pointed, a slightly angular ridge extending from the apex down each side. Anterior surface slightly convex transversely, slightly concave longitudinally; posterior surface transversely rotund, expanding towards the base. Basal portion of crown small, extending less than half the diameter of the central elevation on each side, concave margin thick and recurved upwards. Lateral recurvature extends posteriorly along the margin, nearly to the median line, where the margin is depressed. Anterior margin and base not exposed. Coronal surface deeply punctate, smooth at the apex.

Formation and locality: Mountain Limestone, Armagh. Unique specimen.
Ex coll. Earl of Enniskillen.

Helodus richmondiensis, Davis.

(Pl. LIX., figs. 8, 8*a*.)

Teeth, small, median cone triangularly rotund, with slight lateral prolongation; diameter at the base ·3 inch, height ·2 inch. Crown abruptly elevated to a prominent cone with a slightly acute apex; the anterior surface convex, with a median ridge extending midway between the two lateral ones from the summit to the base. Posterior surface deeply convex longitudinally, transversely rotund. Posterior surface separated on each side from the anterior one by a well-defined, straight ridge, descending from the apex of the cone to its base; one of the ridges is prolonged at its base, and forms a lateral process extending beyond the median cone. Coronal surface covered with enamel, uniformly and deeply punctate. Base hidden by the matrix.

This tooth bears a close resemblance to *Helodus simplex*, Ag., from the coal measures. The form of the central cone is similar, the principal difference consisting in the absence in *H. simplex* of the well-defined and peculiar ridges descending from the summit of the crown to the base. The lateral prolongations of the crown in *H. simplex* are somewhat more extended than in this species.

Formation and locality: Carboniferous Limestone, Richmond, Yorkshire.

Ex coll. Earl of Enniskillen.

Helodus triangularis, Davis.

(Pl. LIX., figs. 9, 9*a*, 9*b*.)

Teeth, transverse section approximately triangular and consisting of a single cone. Height, ·4 of an inch, about equal to the antero-posterior diameter and a little less than the lateral diameter near the base. Summit of cone obtusely pointed and slightly curved backwards. Anterior face convex, separated from the base by a sigmoidal curve, the median part of it extending from the antero-lateral angles, half the length of the tooth, towards the point. The anterior surface forms at its junction with the posterior one angular lateral ridges extending from the apex to the base. The posterior surface is doubly concave, with a wide and prominent median projection separating it into two parts, and expanding towards the base so as to render the form of the tooth almost that of a triangle. Encircling the base of the crown there is a series of imbricating folds, very irregularly arranged. The coronal surface, smooth, enamelled, or minutely punctate; where worn, near the apex, the surface is occasionally roughly pustulate. Base not known.

This species approaches most nearly to the type of *H. simplex*, Agass., from the coal measures, in possessing a single cone and comparatively small base, but it differs materially from that species in its transversely triangular form, in its pointed apex and the minute punctation of its enamelled surface.

Helodus richmondiensis is distinguishable from this species by the presence of a well-defined process or ridge, extending from the apex along the median line to the

base, and also in the line dividing the base from the crown being straight, whilst in *H. triangularis* the line follows a deeply sigmoidal curve.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Helodus expansus, Davis.

(Pl. LIX., figs. 10, 10*a*.)

Chomatodus linearis (partim.) "Ag. Pois. Foss., Vol. III., p. 108, Tab. XII., figs. 5–13.

Teeth, medium size, quadrato-elliptical, length three or four times greater than the breadth, very slightly broader in centre than at the sides. Length, 1·1 inch, breadth in centre ·35 inch. Height of central cone ·2 of an inch. Crown, central portion produced longitudinally to form an acute ridge, extending along the whole length of the tooth; raised in centre to a moderately elevated broad gibbosity. On each side, the ridge is slightly broken up into a number of minor very small projections; transversely the central cone and ridge are moderately thin, near the apex expanding downwards to form a broad base. Anterior surface, convex laterally, and also from apex to base of crown: three or four concentric imbricating folds extend parallel with the anterior margin separating crown and base. Posterior surface, deeply concave, widely expanded from the central ridge to the posterior margin, along which there extends two, sometimes three, imbricating plicæ. Lateral margins anteriorly, rounded and obtuse, forming a right angle with the posterior margin. The anterior and posterior longitudinal plicæ are continued round the lateral margins in close contiguity. Coronal surface, thickly coated with enamel, covered with a very fine reticulation and minutely punctate. Base, equal in depth to the height of the crown; thin, deeply convex anteriorly, less so posteriorly.

This beautiful species possesses the distinctive characters of Helodus; the central cone is less prominent than usual and the several minor cones presenting a denticulated appearance seem to indicate a relationship with Ctenoptychius.

Formation and locality: Carboniferous Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Helodus rudis, M'Coy.

(Pl. LIX., figs. 11, 11a).

Helodus rudis—F. M'Coy,		1848.	"Annals and Mag. Nat. Hist.," 2nd Ser. Vol. II., p. 123
,, ,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 328.
,, ,,	F. J. Pictet,	1854.	"Traité de Palæont.," Vol. II., p. 267.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 631; Pl. 3 K., fig. 4.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 357.

Teeth, "irregularly oblong, subquadrate; sides, steep, irregularly nodulose, or undulate-plicate; crown irregularly gibbous, the highest point a little nearer one end than the other; surface polished, coarsely punctured. Length, seven lines; width, four and a half lines; height, two and a half lines,"—*M'Coy.*

The curiously irregular humplike figure and subquadrate form of the base of this species distinguish it from its congeners; the steep striated side is also peculiar.

Formation and locality: Mountain Limestone, Armagh.
Ex. coll. Admiral Jones, Geological Society, London.

Genus Pleurodus, Agass., indet.

Teeth, small, triangularly or obliquely ovate; anterior extremity more or less pointed expanding backwards, nodose median ridge extends along longer axis of the crown, laterally thin; margins more or less expanded and deeply indented Surface covered with enamel; punctate, occasionally reticulate. Base thin, coextensive with crown, hollow beneath.

The species hitherto described from British strata have been found only in the Coal Measures. The horizon of the genus is extended by the discovery of the species here described, downwards to the Mountain Limestone.

Pleurodus woodi, Davis.

(Pl. LIX., figs. 12–15).

Teeth, small; length ·3 of an inch; greatest width equal to the length; more or less triangularly-ovate in outline. Crown, convex; laterally expanded; median line prominently developed to form a ridge extending across the greatest diameter. Median ridge divided into five or fewer projecting nodes, from which lateral ridges descend to the external margins; these are terminally separated by deep indentations of the margins; one end of the tooth, probably the posterior one, is wider and somewhat rounded, the sides gradually taper to the opposite end. Surface of the projections of the median ridge are frequently worn by attrition: uniformly and somewhat coarsely punctate. Base or root thin, porous, conforms generally to the outline of the crown; proportionately concave to the convexity of the crown.

The teeth vary in outline, the anterior margins in some are deeply indented, in others scarcely at all. A few specimens are very long in proportion to the width.

In recognition of the services of the late Mr. Wood, of Richmond in Yorkshire, to palæontological science, I have pleasure in appending his name to distinguish these teeth specifically.

Formation and locality: Mountain Limestone, Richmond in Yorkshire.
Ex. coll. Reed Collection, York Museum; Mr. Horne, Wensleydale.

Group—Psammodontidæ. L. G. de Koninck.

Genus—Psammodus, Agassiz.

Teeth, large and flat, more or less rectangular in form; root very thick, as large as, and similar in form to, the crown. Surface of the crown covered with small pores, raised in rugose wrinkles or worn smooth; surface of the crown sometimes raised near one or both lateral edges.

Psammodus rugosus, Agass.

(Pl. LVI., figs. 1–7; LVII., figs. 1–7).

Dens tritor rugosus—Miller MSS.		"Catalogue of Bristol Museum."
Psammodus rugosus—L. Agassiz,	1833.	"Poissous Fossiles," Vol. III., p. 111, pl. xii., fig. 14–18; pl. xix., fig. 15.
,, porosus ,,	1833.	"Ibid," Vol. III., p. 112, pl. xiii., figs. 1–18,
,, rugosus—J. E. Portlock,	1843.	"Rept. on Geol., Londonderry, &c.," p. 465. p. xiv.a, fig. 1.
,, porosus ,,	,,	"Ibid," p. 466, pl. xiv. a, fig. 2.
,, rugosus —L. G. de Koninck,	1844.	"Descr. des Anim. Foss. du Terr.-Carb. de la Belgique," p. 616, pl. liii., fig. 8.
,, porosus ,,	,,	"Ibid," p. 616, pl. lv., fig. 4.
,, rugosus—C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I. pl. iii., p. 336.
,, porosus ,,	,,	"Ibid," Vol. I., pl. iii., p. 336.
,, rugosus—H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 1048.
,, porosus ,,	,,	"Ibid," p. 1048.
,, ,, ,,	1849.	"Enumerator Palæont.," p. 647.
,, canaliculatus—F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist." 2nd Ser., Vol. II., p. 112.
,, rugosus—H. G. Bronn,	1849.	"Enumerator Palæont.," p. 647.
,, porosus—F. A. Quenstrot,	1852.	"Handb. d. Petrefakt., p. 188, pl. xiii., fig. 61.
,, rugosus—J. Morris,	1854.	"Cat. Brit. Foss.," p. 341.
,, porosus ,,	,,	"Ibid," p. 341.
,, rugosus—F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 266, pl. xxxviii., fig. 28.
,, porosus ,,	1854.	"Ibid," Vol. II., p. 266.
,, canaliculatus ,,	,,	"Ibid," Vol. II., p. 266.
,, rugosus—F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 644.
,, ,, var porosus ,,	,,	"Ibid," p. 644.
,, canaliculatus ,,	,,	"Ibid," p. 643, pl. 3 G, fig. 12.
,, porosus—F. Roemer,	1856.	"In H. G. Bronn Lethœa geogn.," Vol. I. p. 706, pl. ix., fig. 2.
,, ,, E. d'Eichwald,	1860.	"Lethœa rossica," Vol. I., p. 1547.
,, rugosus—Morris & Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101.
,, porosus ,,	,,	"Ibid," Vol. XVIII., p. 101.
,, rugosus—H. Rowanowsky,	1864.	"Bull. d. l. Soc. imp. des Nat. de Moscou," p. 158, pl. iii., figs. 3 and 5.
,, porosus ,,	,,	"Ibid," p. 158, pl. iii., fig. 4.

Psammodus rugosus—Newberry and Worthen,		1866.	"Geol. Surv. of Illinois," Vol. II., p. 108, pl. xi., fig. 3.
,,	porosus ,,	1866.	"Ibid," Vol. II., p. 107, pl. xi., fig. 1.
,,	reticulatus (?) ,,	1866.	"Ibid," p. 109, pl. xi., fig. 9.
,,	rugosus—Enniskillen,	1869.	"Alph. Cat. Type Fossil Fishes," p. 7.
,,	inflexus (?)—H. Trautschold,	1874.	"Fischreste aus dem Devon. des Gouver. Toula, p. 11, pl. ii., fig. 12.
,,	porosus—F. Roemer,	1876.	"Lethœa palæoz.," pl. xlvii., fig. 2.
,,	,, W. H. Baily,	1875.	"Figs. of Char. Brit. Foss.," p. 120, pl. xli., fig. 9.
,,	,, J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 365.
,,	rugosus ,,	,,	"Ibid," 365.
,,	canaliculus ,,	,,	,, 363.
,,	reticulatus ,,	,,	,, 364.
,,	porosus—L. G. de Koninck,	,,	"Fauna du Calc. Carb. de la Belgique," p. 41, pl. v., figs. 1–5.

Teeth, large, thick, more or less flat; crown irregularly subtrapezoidal or oblong in form, occasionally nearly rectangular, sometimes triangular. Antero-posterior margins sub-parallel, occasionally nearly straight, oftener concavo-convex. Convex or anterior margin shortest. One of the lateral margins generally straight, the other oblique, forming a more or less obtuse angle with the anterior margin, and with the posterior margin extending backwards so as to form an acutely projecting angle. Coronal surface hollowed in the middle, raised towards each lateral margin; or the central portion is raised or convex, in all probability indicating opposing teeth. Entire surface covered with close sinuous ridges, roughly parallel with the antero-posterior margins; in worn examples the wrinkles or ridges have been rubbed down, either over a part or the whole of the surface, where it exhibits a smooth, uniformly, and coarsely granulo-punctate surface, formed by the superficial exposure of the openings of the medullary tubes. Root of the tooth varies in thickness, usually inbevelled from the crown, occasionally inbevelled in front and on each side, whilst the posterior margin projects in a proportionate degree.

M. de Koninck (Fauna du Calcaire Carbonifère de la Belgique, p. 42) considers that *Psammodus porosus* should be retained as the type, and describes the teeth under that name; on the other hand, Prof. M'Coy describes the specimens under the title *Psammodus rugosus*, and as the unworn teeth all exhibit the characters of the surface which led Prof. Agassiz to consider the species separate from *P. porosus*, and the distinguishing characteristics of the latter are due to the grinding action in using the teeth, it appears that the specific name selected by Prof. M'Coy should be retained. It has also precedence in the old Catalogue of the Bristol Museum in which the teeth are styled *Dens tritor rugosus*.

The oblong form, in which the antero-posterior diameter greatly exceeds that between the sides of the teeth, described by Prof. M'Coy as a separate species *Psammodus canaliculatus*, must also be included in the species *P. rugosus*. It

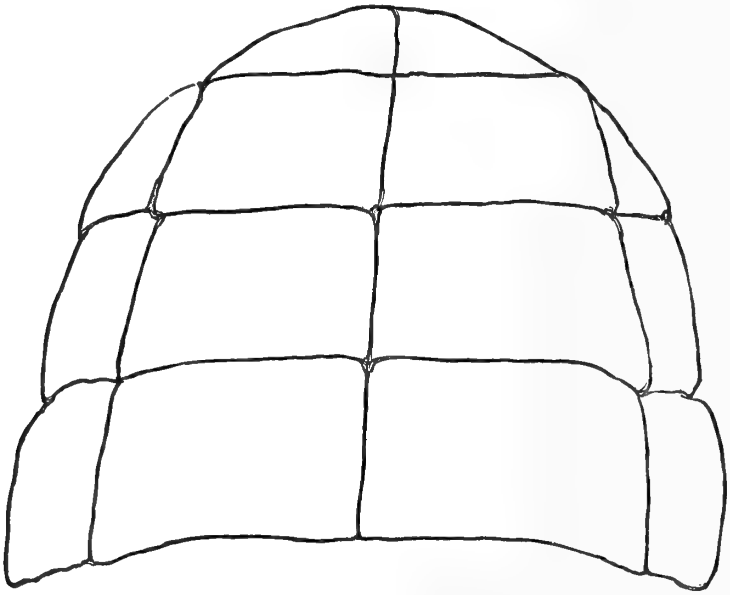
exhibits the same surface markings in unworn specimens as well as the smooth and punctate appearance where the rugose markings have been removed by trituration. The rugosities in this form extend across the short diameter of the tooth, and if, as appears probable, this form was placed laterally alongside the larger specimens, the rugose markings of each would lie parallel in the same direction.

A reference to the figures on Plates LVI. and LVII. will illustrate better than any amount of description the varied forms assumed by these teeth. The outline most commonly observed is the one shown in Pl. LVI., fig. 1, a magnificent specimen from the collection of Lord Enniskillen. The concave surface is the posterior part of the tooth and was probably joined to another tooth; the anterior margin is convex, the right side, which is the median line in the mouth, is straight, whilst the opposite one expands obliquely backwards. In the accompanying figure, 1 b, representing a section of the tooth, the crown is represented ·2 of an inch in depth, whilst the root varies from ·4 to ·6 in the central part, the lateral portions being at the straight side ·8 of an inch, and on the oblique or external side it is 1·1 inch in depth. Prof. de Koninck (Fauna du Calcaire Carbonifère de la Belgique, p. 42) has ventured an opinion that the teeth were arranged in three rows of four teeth, each containing two of the broad teeth spoken of above, and on each side a narrow tooth (the *P. canaliculatus* of M'Coy). After very carefully studying the large collection of specimens in the Enniskillen and other collections, it appears very probable that a modification of this arrangement may have been the one which existed. Prof. de Koninck remarks, "Je ferai remarquer que cette dernière disposition n'est nullement hypothétique comme ou pourrait le croire; je l'ai observée sur une specimen de la collection de M. Neilson de Glasgow et dont les trois dents conservées en place sont exactment reproduites par le dessin. Il est donc probable que pendent la vie de l'animal ces dents étaient plus ou moins mobiles et séparées les unes des autres par une légère couche de matière cartilagineuse ou fibreuse."

The form of the large teeth serves to confirm the opinions stated above, because in every instance either the right or left lateral margin is straight, proving that whilst the obliquely inclined margin conformed to the outer shape of the jaw, the straight side was adapted to fit the straight edge of the tooth on the opposite ramus of the jaw. In addition to the tooth shewn on Pl. LVI., fig. 1, a less common form is represented on Pl. LVII., fig. 7, the diameter of which is twice or three times greater between the antero-posterior margins than between the lateral ones, and as stated the rugosities when present lie across the surface parallel with the shorter diameter. The teeth are generally slightly curved, concave on the inner margin, convex on the outer one; the outer postero-lateral angle is produced acutely as in the larger teeth, and served to support the antero-lateral extremity of the succeeding tooth. Examples of this form occupied the lateral extremities of each jaw. A third somewhat persistent form is represented on Pl. LVII., fig. 3. It is similar to the last, except that its anterior margin is much contracted in

width, almost reduced to a point and considerably curved inwards. It was probably attached to the lateral margin of the first pair of dental plates, its accuminate anterior extremity conforming to the curvature of the jaw.

There is still a triangular form (Pl. LVI., figs. 6, 7) which has been found abundantly at Bristol, but is less frequent, or absent, from the limestones of Armagh. They may have occupied a position anterior to the large central teeth or on each side the most anterior one. A diagrammatic representation of the recon-



structed jaw is here given from which the arrangement of the teeth indicated above may be inferred.

An occasional tooth exhibits a more or less gibbous surface of the crown, this appears to be an abnormal character, possibly due to some imperfection of the corresponding tooth of the opposite jaw.

Group.—Copodontidæ, Davis.

In the "Poissons Fossiles," Vol. III., page 174, an undescribed tooth is named *Psammodus cornutus* by Prof. Agassiz. The species is again referred to by Portlock in the "Geological report of Londonderry, Fermanagh, Armagh," &c., p. 466, and a figure is given of it (plate xiv.*a*, fig. 3). Portlock's description consists of some observations made by Captain Jones as follows: "Several specimens have been obtained where two teeth were in their natural position. The form is quite distinct from that of its congeners; it is trapezoidal, having a long and a short side, the long being more or less concave, the short more or less convex, and, when joined together, the convex side of the one tooth fitted into the concave side of the adjacent one." The specimen figured bears a great resemblance, to the figure of *Characodus angulatus* to be hereafter described. *Psammodus cornutus* is again

described by Prof. M'Coy in Brit. Palæoz. Foss., p. 643, but no figure is given of it. It is described as trapezoidal: lateral sides long, straight, equal; posterior side shorter than the lateral ones and concave; anterior side shortest, slightly convex. This is the description of a tooth longer than broad, whilst the one figured by Portlock is considerably broader than long.

In June, 1859, the late Prof. Agassiz visited this country, and devoted much time to a re-examination of the large collection of palates from the Mountain Limestone, which form a conspicuous element in the collection of fossil fishes gathered by the Earl of Enniskillen.

The genus *Psammodus* amongst others received the attention of that skilled Ichthyologist and the species *P. cornutus* was justly eliminated from the genus. During the twenty years subsequent to the publication of the great work on Fossil Fishes by Agassiz, numerous additions had been made to the collections of Carboniferous Limestone fish remains, and consequently improved opportunities for their study and determination were available. The teeth hitherto included in the genus Psammodus, which were named *P. cornutus* in the "Poissons Fossiles" but were undescribed, were discovered to be not only of distinct generic character, but to represent more than one genus of fishes. Prof. Agassiz rearranged the several specimens, and appended to them new generic and specific names, intending at some future opportunity to publish descriptions and plates of them, with a general revision of the whole group of fish remains from the Carboniferous Limestone. Unfortunately this opportunity did not occurr, and the death of Professor Agassiz has now rendered it impossible. The determinations and nomenclature of Agassiz are here adhered to and retained, or when any change appeared necessary it has been duly noted and explained.

The specimens comprised in the several genera indicated by Prof. Agassiz are comparatively numerous in the Limestone quarried near Armagh; but notwithstanding a few specimens have been obtained, they are very rare from other localities; a large majority of the species are represented by a fairly numerous set of examples, and in no instance are they founded on unique specimens.

In some respects they approach the Psammodont group of fish palates, they were more or less flat and pavement-like in their arrangement; but as to the details of that arrangement there is little or no evidence. The teeth of *Copodus cornutus*, Ag., which in many respects must be considered the type of the group, have been found associated in pairs; they are very divergent in form. Whether, a large or small number of teeth were implanted on each jaw is undetermined; it is necessary to await the advent of more complete examples, and should such be discovered, it is quite possible that a considerable rearrangement of the genera and species which are included in the group may be found necessary. At the present moment the genera appear well defined and established on a sound basis, but the whole course of palæontological research has proved that the ideas conceived of genera and species

to-day, are greatly modified or completely changed by the discoveries of to-morrow, that nothing can be regarded as fixed, and it is by the result of repeated applications only that the palæontologist is enabled to grasp the truth.

It is suggested that the whole of the genera presently to be described be regarded as a separate group—the COPODONTIDÆ. In many respects they present features in common and appear to form a natural group. The name of the most numerous, best known and most characteristic genus naturally suggests itself as the fittest on which to base the name of the group.

Genus Copodus, Ag., MSS.

Copodus—L. Agassiz, 1859. MSS. Enniskillen collection.

Palatal teeth of medium size, thick, sub-quadrate in outline; crown, either flat, slightly convex, or slightly concave; enamelled surface uniformly punctate; anterior margin convex, narrower than the posterior one; posterior margin, concave with postero-lateral prolongations; base, same form as crown, strong, osseous, and roughly striated.

Copodus cornutus, Agass. MSS.

(Pl. LVIII., figs. 1–5.)

Psammodus cornutus—L. Agassiz,		1838.	"Poissons Fossiles," Vol. III., p. 174.
,, ,,	J. E. Portlock,	1843.	"Rept. Geol. Londonderry," &c., p. 461., Pl. xiva. fig. 3.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pl. iii., p. 336.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 1048.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 647.
,, ,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 340.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 266.
,, ,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 643,
Copodus cornutus—L. Agassiz,		1859.	"MSS. Enniskillen collection.
,, lunulatus	,,	1859.	,, ,, ,,
,, cornutus—Morris and Roberts,		1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, lunulatus	,,	1862.	,, ,, ,, ,, ,, ,,
,, cornutus—Enniskillen,		1869.	"Alph. Cat. Type Spec. Foss. Fish.," p. 4.
,, lunulatus	,,	1869.	,, ,, ,, ,,
,, cornutus—J. J. Bigsby,		1878.	"Thesaurus Devon. Carb.," p. 351.
,, lunulatus	,,	1878.	,, ,, ,,

Teeth, sub-quadrate, anterior margin circular, lateral ones nearly straight and increasing in breadth backwards. Average specimens ·75 of an inch in length, and about the same breadth between the latero-posterior angles, which are produced beyond the posterior portion of the tooth in hornlike processes. Largest specimen is 1·1 inch broad, posteriorly diminishing to ·65 anteriorly. Length along the median line ·85 of an inch, along the side 1·15 of an inch. The same specimen is

·3 of an inch in thickness at a distance of one-third the length of the tooth from the posterior margin and diminishes to ·2 in front. Crown; either convex or concave in each, presenting the appearance of having been considerably worn by attrition towards the anterior extremity. The surface of the convex teeth are raised in the centre and along each lateral margin with a slight lateral depression within the margin; the concave teeth are hollowed throughout with raised lateral margins. Surface covered with a thick coating of enamel anteriorly, where much used and worn the enamel is thin or quite removed; closely covered with minute punctures. Anterior border circular, ganoine or enamel slightly projecting beyond the bony structure of the base, and forming with the latter an acute angle. Laterally straight or slightly convex, retreating towards the base. Posterior border concave with the base projecting beyond the crown to give support to the anterior portion of the succeeding tooth. Latero-posterior angles produced in a line with the lateral margin so as to form hornshaped extensions, widely separated by the posterior surface of the tooth. Base; surface roughly striated longitudinally, slightly concave, thickest in the centre and thinning off towards each side.

This species may be distinguished by the horn-like prolongations from the latero-posterior angles, one-third or more of the length of the central axis of the crown, they are continued in a straight line with the sides of the tooth, and are widely separated from each other posteriorly.

A second palate was considered by Prof. Agassiz to constitute a separate species, to which the name of *C. lunulatus* was given. The discovery of specimens with *Copodus cornutus,* and *C. lunulatus* attached in such a position as to prove that they are only one species, renders the latter species superfluous, and it is therefore included in the former.

The second and smaller teeth are more or less crescentic in outline, anterior margin circular, laterally much produced, posterior margin slightly curved or straight; the length of the tooth is ·35 of an inch along the median line, the breadth is ·75 of an inch. Transverse section, basal outline circular; greatest thickness in centre, ·25 of an inch, tapering laterally to ·12 of an inch. Crown, convex, oval in centre, depressed towards lateral extensions, which are again raised. Surface covered with enamel, profusely punctate, the punctures descending through the enamel to the bony structure of the base. Anterior border, slightly circular, produced at each side to form in conjunction with the more strongly curved posterior margin, aliform lateral processes. The latter vary in size and form in different specimens, in some obtusely rounded, in others acuminate. From the anterior and posterior margins the base recedes, and is narrower than the crown, laterally the base extends beyond the prolongations of the coronal surface.

The convexity of the anterior surface corresponds with the concave surface of the posterior margin of the larger tooth, as shewn in the figure (Pl. LVIII., figs. 2, 5). Both these surfaces exhibit considerable modification in form in different

specimens, which, rendered necessary to the proper fitting of their respective surfaces, affords an additional proof of the identity of the species.

Formation and locality : Carboniferous Limestone, Armagh ; tolerably common. Rare in the dark Lower Limestone at Lowick (M'Coy).

Ex Coll. Earl of Enniskillen.

Copodus furcatus, Agass. MSS.

(Pl. LVIII., fig. 16.)

Copodus furcatus—L. Agassiz,	1859.	MSS. Enniskillen Collection.
„ falcatus (?)—Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
„ furcatus—Enniskillen,	1869.	"Cat. Types Fossil Fish," p. 4.
„ falcatus (?)—J. J. Bigsby,	1878.	"Thesaurus Devonico Carb.," p. 354.

Teeth, sub-quadrate, deeply forked posteriorly ; breadth, ·8 of an inch, length, ·9 of an inch from the anterior margin to the extremity of the fork ; along the median line to the point of bifurcation the length is ·7 of an inch. Crown, convex, with lateral margins raised, forming a slight, longitudinal concavity along each side ; convexity in antero-central part much abraded by use. Posteriorly, the coronal surface is depressed along the median line, prior to the bifurcation. The surface is coated with enamel, and pierced by innumerable irregularly-disposed punctures. Anterior margin straight in middle, with obtusely-rounded corners. Laterally, the crown is nearly straight to the extremity of the postero-lateral angles, where the diameter is slightly contracted. The postero-lateral are formed by the posterior margin, which makes an acute angle with the lateral ones on each side, and meeting in the median axis of the tooth, constitutes an approximate right-angled bifurcation. Base equal in size and same form as the crown, characterized by the ordinary structural appearance.

This species offers some resemblance to *C. cornutus*. The form of the anterior portion of the tooth is very similar, but the posterior is quite distinct. The bifurcation from the centre of the tooth in this species forms a specific difference which cannot be mistaken. The pittings in the coronal enamel of *C. furcatus* are less distinct, and separated by wider expanses of enamel than in any other species of this genus.

Formation and locality : Mountain or Carboniferous Limestone, Armagh, Ireland.

Ex coll. Earl of Enniskillen.

Copodus spatulatus, Agass. MSS.

(Pl. LVIII., fig. 7).

Copodus spatulatus—L. Agassiz,	1859.	MSS. Enniskillen Collection.
,, ,, Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 100.
,, ,, Enniskillen,	1869.	"Cat. Types Fossil Fishes," p. 4.
,, ,, J. J. Bigsby,	1878.	"Thes. Devonico-Carb.," p. 351.

Teeth, square, with rounded anterior angles; at each postero-lateral angle there is a wing-like projection from the body of the tooth, and at a distance of one-sixth the diameter of the tooth is a suture parallel with the posterior margin. Length of the tooth, ·9 of an inch; breadth across centre of the crown, ·8 of an inch, diminishes anteriorly to ·6 of an inch, and increases backwards to 1 inch. Transverse section exhibits a convex base and slightly convex crown; greatest diameter, ·3 of an inch, thinning towards each side to a little more than ·1 of an inch. The thickness diminishes slightly towards the anterior extremity, and more so towards the posterior. Crown, convex in central portion, with a raised broadly circular rim, forming the lateral borders; anterior portion deeply excavated by attrition during mastication; posterior part of the tooth depressed and separated by a distinct suture-like groove from the larger coronal area. The latter is covered with the usual minute pittings; the narrow posterior portion is less distinctly marked and presents a reticulated surface. Anterior margin of crown straight in the median portion, projecting beyond the extremity of the base; antero-lateral angles rounded, sides slightly convex, and expanded towards the back of the tooth into a projection from the enamelled surface of the crown. The posterior margin for the major part straight, each latero-posterior angle slightly produced and pointed backwards. The latero-posterior expansions in this species are from the sides, whilst in *C. cornutus* and *C. furcatus* they were developed from the body of the crown backwards. In *C. spatulatus* the enamel of the coronal surface does not extend, as in the species already described, so as to envelop the lateral expansion, but its surface is rough, pertaining more to the bony character of the base. The principal distinguishing feature, however, consists in the suture-like depression running parallel to the posterior margin; in no other species does this occur.

Formation and locality: Carboniferous Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Copodus minimus, Davis.

(Pl. LVIII., fig. 8.)

Teeth, small, equilateral, angular, in general form differing from all the other species. Length along the median axis, ·4 of an inch; breadth across posterior extremity, ·35, diminishing gradually to the anterior, where the breadth is ·2 of an inch. Crown slightly convex from front to back, straight from side to side;

surface, enamelled and covered with irregularly disposed minute punctures. Anterior margin straight or slightly convex; with the lateral margins it forms obtuse-angled triangles; sides straight, widening to the junction with posterior surface. Posterior margin slightly convex in the middle, depressed prior to its forming the latero-posterior angles on each side. Latero-posterior angles acute, extending a short distance beyond the general posterior surface, but not so decidedly produced as in the previous specimens. Base hidden.

The teeth vary a little in size, the largest representative being ·6 of an inch in length. The crown in the larger specimens is much worn, and quite concave towards the anterior margin.

This little tooth is more rectangular than either of the species described. In form it more nearly approaches to *C. cornutus*, but it differs essentially from the small or young specimens of that species; they possess the circular or convex anterior margin, slightly rounded sides and well-developed posterior concavity, with the horn-like prominences; none of these characters, however, pertain to *Copodus minimus*. The specimens are from the Mountain Limestone of Richmond, and they are the only examples which have been found in that locality.

Formation and locality: Carboniferous Limestone, Richmond, Yorkshire.

Ex. coll. Earl of Enniskillen.

Genus—Labodus, Agass. MSS.

Labodus—L. Agassiz, 1859. MSS. Enniskillen Collection.

Palatal teeth, medium size, more or less rhomboidal in outline, thick. Crown, plain or convex, with a raised lateral margin, surface uniformly punctate; anterior margin straight or slightly sinuous; lateral margins convex; posterior well rounded; base much broader, but more contracted medially than the crown; thick, osseous, and extending beyond the coronal surface, so as to form lateral extensions, culminating at the latero-posterior angles in diagonal projections, higher and more prominent than the enamelled surface of the crown.

Labodus prototypus, Agass. MSS.

(Pl. LVIII., figs. 9–11.)

Labodus	prototypus—	L. Agassiz,	1859.	"MSS. Enniskillen Collection."
,,	,,	Morris & Roberts,	1862.	"Quart. Jour. Geol. Surv.," Vol. XVIII., p. 101.
,,	,,	Enniskillen,	1869.	"Cat. Type Fossil Fishes."
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devon. Carb.," p. 357.

Teeth, more or less rhomboidal in form; breadth of enamelled portion of crown, ·9 of an inch, beyond which extend lateral processes, giving a total breadth of 1·2 inches. The length of the crown along the median axis is ·65 of an inch. Crown, convex from anterior to posterior surface; anterior half much worn by attrition, and more or less concave in consequence. The central portion of the crown, ·55 of

an inch in width, is convex. On each side this convexity, parallel with the lateral margin of the crown, extends a flat groove, ·1 of an inch in width; beyond this the surface is again raised, and forms prominent lateral ridges, as high or a little higher than the central convex surface. The ridges form the boundary of the coronal surface. Beyond the crown proper there is on each side a bold extension of the bony structure of the base along the whole lateral surface. Commencing with a slight projection near the anterior lateral angle, they become gradually wider and more prominent towards the posterior angle of the crown, where they are developed into processes extending diagonally beyond the postero-lateral angle of the enamelled surface to a distance of ·25 of an inch, and standing at a higher elevation from the base than the central convexity of the crown. Anterior margin corresponds in a greater or less degree to the form of the crown, convex in the centre, with depressions on each side, and a slightly prominent antero-lateral angle. Lateral margin of enamelled crown convex; osseous extension beyond this nearly straight, with persistent expansion in breadth to the posterior angle; posterior margin rounded, forming with the sides a more or less acute angle; surface of crown uniformly punctate; the minute orifices rather pentagonal than circular. Base, breadth 1·25 inch diameter from back to front in central part; ·4 of an inch at each side, it expands to ·6 of an inch. In its longest diameter the surface is broadly convex, in the opposite direction concave; greatest thickness, ·3 of an inch in the centre of the tooth; diminishes in each direction; thinnest at the lateral extremities, which are ·175 of an inch in thickness.

The form of the base does not correspond with that of the crown, as will be seen by a reference to the figures. The posterior circular portion of the crown projects considerably beyond the surface of the base; and in the same manner, but to a smaller extent, does the anterior margin.

The several teeth vary considerably in size and form, and their surface configuration depends greatly on the amount of attrition to which they have been subjected. The specimen selected for description is of average size, and its crown in a good state of preservation. Examples occur in which the crown surface—*i.e.*, the surface covered with enamel—is almost square in form, the average being about one and a half times broader than long. A few specimens, seemingly derived from very aged fish, are deeply worn, and present the appearance of three wide, deep, longitudinal grooves—one in the centre and one on each side—with smaller intermediate ridges, the front of the tooth very thin, and the anterior margin quite worn away.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Labodus planus, Ag. MSS.

(Pl. LVIII., figs. 12–14.)

Labodus planus—	L. Agassiz,	1859.	MSS., Enniskillen Coll.
„ „	Morris and Roberts,	1862.	"Quar. J. Geol. Soc.," Vol. XVIII., p. 101.
„ „	Enniskillen,	1867.	"Cat. Type Speci.," p. 5.
„ „	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 357.

Teeth, more generally rounded in outline than *L. prototypus*, smaller, and the lateral expansions of the osseous base less prominent. Length of crown along median axis, ·7 of an inch, breadth ·6 of an inch. Crown flat or very slightly convex, ridge bounding the crown laterally slightly raised ; anterior part more or less concave from attrition. Coronal surface covered with an exquisite arrangement of pittings, presenting the magnified appearance of the facets of a butterfly's eye ; the punctations increase slightly in size towards each side. Anterior margin slightly concave, antero-lateral angles obtusely curved ; lateral margins straight, expanding a little towards the posterior aspect. Central part of the posterior margin convex, with an incurving towards the postero-lateral angles, which are more or less prominent. Base less constricted than in *L. prototypus*, between the anterior and posterior margins, wider than crown ·3 of an inch thick in centre, tapering near each side to an acute angle ; transverse section convex, slightly depressed on each side the median line ; longitudinally the surface is concave. The base extends beyond the crown on each side, but not to so large an extent as in *L. prototypus*, the latero-posterior angles are produced to the extent of ·1 of an inch, or in some instances rather more diagonally in continuation of the angle of the crown.

This species differs from *L. prototypus* in its evenly spread crown, round anterior angles, and in the lateral prolongations of the base forming a less conspicuous mass on each side the crown, as well as in minor details in the basal portion.

Formation and locality : Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Mesogomphus, Agass. MSS.

Mesogomphus—L. Agassiz, 1859. MSS., Enniskillen Collection.

Palatal teeth ; outline tongue-shaped, posterior diameter equal to length, narrowing towards the front. Crown slightly convex, depressed posteriorly with a median well-defined semi-circular suture extending inwards from the posterior margin ; lateral borders slightly raised ; coronal surface punctate. Anterior margin circular, continued, and gradually expanding along the lateral margins ; posterior margin convex, postero-lateral angles obtusely rounded. Base thick, transversely convex, similar form to crown but extending beyond its posterior margin.

Mesogomphus lingua, Agass. (MSS.)

(Pl. LVIII., fig. 16.)

Mesogomphus lingua—	L. Agassiz,	1859.	MSS., Enniskillen Collection.	
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101	
,, ,,	Enniskillen,	1869.	"Catal. Type Specimens," p. 6.	
,, ,,	J. J. Bigsby,	1878.	"Thes. Devonico-Carb.," p. 359.	

Teeth, General form, as indicated by the specific name, is tongue-shaped. Length along the median axis ·9 of an inch, greatest breadth at posterior portion is the same as the length. The breadth gradually diminishes to the front, ending in a rounded anterior extremity. Crown slightly convex in each direction; lateral borders raised; anterior portion considerably worn by attrition, especially near the extremity. From the centre of the crown backwards the surface is depressed towards the middle of the posterior margin, and a well-defined semi-circular suture like depression extends from the posterior margin towards the centre; the portion of the crown separated by this suture, occupies rather more than the central third of the margin, and extends ·25 of an inch over the coronal surface, it is marked by two or three transverse ridges extending across its surface; the whole surface of the crown is minutely punctate. Anterior termination circular, gradually expanding laterally towards the posterior margin, which is convex. Postero-lateral angles obtusely rounded. Base thickest in the middle, thinner towards each side; from the posterior to the anterior extremities about the same thickness is maintained; the form of the base is the counterpart of that of the crown. The enamel of the crown projects anteriorly above the base, whilst posteriorly the base extends beyond the crown, especially at each of the postero-lateral angles.

Formation and locality: Carboniferous Limestone, Armagh.

Ex. coll. Earl of Enniskillen.

Genus.—Pleurogomphus, Agass. (MSS.)

Pleurogomphus—L. Agassiz, 1859. MSS., Enniskillen Collection.

Palatal teeth: outline sub-quadrate, medium size, length and breadth equal. Crown, concave, lateral borders slightly prominent, surface uniformly punctate; posterior third of coronal surface depressed, lateral third on each side separated by deep sulci or sutures. Anterior margin obtusely rounded, lateral and posterior margins straight. Postero-lateral angles produced acutely. Base thick, striated, longitudinally concave; transversely convex extending slightly beyond the lateral margin of crown; anteriorly and posteriorly shorter than crown.

In some respects Pleurogomphus bears a resemblance to *Copodus cornutus,* it has the closely approximating outline of the coronal surface, but that of the base is quite different; in the latter the base is produced to form largely extended postero-

lateral angles, and posteriorly the base extends beyond the coronal surface, apparently to give support to a succeeding tooth. This is not so in Pleurogomphus ; the distinguishing characteristic of the genus is in the division of the posterior area into three parts by sulci, and in this it mainly differs from Mesogomphus in which there is only one suture, and that a median one.

Pleurogomphus auriculatus, Agass. MSS.

(Pl. LVIII., figs. 15, 15*a*, 15*b*.)

Pleurogomphus auriculatus—	L. Agassiz,	1859.	MSS. Enniskillen Coll.
" "	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101.
" "	Enniskillen,	1869.	"Catal. Type Spec.," p. 7.
" "	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 363.

Teeth, sub-quadrate in outline, rounded at the anterior angles ; length, along median axis, ·75 of an inch ; breadth, same as length. Crown, concave ; concavity increased at the anterior portion by attrition ; lateral borders very slightly raised. Posterior third of the coronal surface is obliquely depressed, and on each of the latero-posterior portions there is a circular sulcus or suture, very similar to the median one of Mesogomphus, except that in this genus there are two sutures, cutting off or separating portions of the posterior surface at each corner, and leaving the central portion connected with the crown. The sutures divide the posterior margin into three equal parts, and extending longitudinally for a distance of about ·2 of an inch, they curve in each case towards the lateral margins, to which they approximate at ·1 of an inch from the postero-lateral angle. The surface of the separated portions is convex in front, the back portion receding. The whole of the coronal surface is punctate, and where not too much worn is coated with enamel. On the anterior portion, where the enamel has quite disappeared, the punctate character of the surface is still retained. Anterior margin broadly circular ; lateral margins straight. The enamelled surface forming the anterior margin projects beyond the base. Posteriorly the margin is straight, except that each postero-lateral border is produced, and forms an acutely-projecting angle. Base thick, strong ; longitudinally striated and concave ; transversely it is deeply convex, thinning towards each lateral margin, and extending slightly beyond the crown. The posterior margin of the base conforms generally to that of the crown, but like the anterior, does not extend so far as the coronal surface.

Formation and locality : Carboniferous Limestone, Armagh ; a unique example.
Ex coll. Earl of Enniskillen.

Genus.—Rhymodus, Agass. MSS.

Rhymodus—L. Agassiz, 1859. MSS. Enniskillen Collection.

Palatal teeth, transversely oblong, of medium size, the length less than half of the breadth. Crown, convex in centre, laterally depressed, borders prominent. Coronal surface, coated uniformly with enamel, slightly punctate. Anterior margin, deeply concave, concavity occasionally occupied by a crescent-shaped portion of the crown; posterior and lateral margins convex, postero-lateral angles acuminate. Base, thick, smooth, longitudinally shorter than crown; transversely convex; extending beyond the coronal margin, and forming an acute angle with the superior surface of the tooth.

Rhymodus transversus, Ag. MSS.

(Pl. LVIII., fig. 17.)

Rhymodus transversus—	L. Agassiz,	1859.	MSS. Enniskillen Coll.
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	Enniskillen,	1869.	"Cat. Type Spec.," p. 8.
,, ,,	J. J. Bigsby,	1878.	"Thes. Dev.-Carb.," p. 365.

Teeth, transversely oblong, thick, variable in size. Length of crown, ·45 of an inch; breadth, ·9 of an inch, beyond which an osseous prolongation of the base extends ·12 of an inch on each side, making the total breadth 1·14 inch. Crown longitudinally and transversely convex in centre; a depression extends across the surface on each side, parallel to the lateral borders, which are raised and prominent. Surface of crown, covered with enamel; uniformly, but indistinctly punctate. Anterior margin of crown sinuous, central portion deeply concave; antero-lateral angles, obtusely rounded. Lateral margins convex; posterior, well rounded in central part, a depression on each side, corresponding to the one on the surface; postero-lateral angles slightly acuminate. Laterally, beyond the coronal surface there is an extension of the osseous base, most largely developed at the postero-lateral angles. Base, conforms generally to the outline of the crown, ·3 of an inch thick, transverse section, convex; thinning off laterally to an acute angle, with superior face, longitudinally striated, smooth.

Figure 17 represents a specimen in which the deeply concave anterior surface is occupied by an enamelled, crescent-shaped portion of the tooth, the division being distinctly marked by the presence of a suture-like depression. The anterior border in this specimen is straight.

Rhymodus oblongus, Davis.

(Pl. LVIII., fig. 18.)

Teeth, oblong in contour; length less than half the breadth; thickness equal to length; crown, convex in both directions; lateral borders slightly raised. A ridge, ·15 of an inch in breadth, extends across the coronal surface

parallel to the sinuous margin of the anterior extremity of the tooth; surface thickly coated with enamel; rugose; folds extending longitudinally across the crown. Lateral margin, crown extended beyond the base, concave in centre, convex on each side, the convexity being continued to the lateral margins, which, towards the posterior angles, are straight; posterior margin of tooth straight; postero-lateral angles, acuminate, slightly produced posteriorly. Base, thick, osseous, striated, transversely convex, ·95 of an inch across. Posteriorly the base extends beyond the crown; laterally it is produced on each side of the crown, forming aliform processes, widest near the postero-lateral angle, where they are ·15 of an inch in breadth. Length of crown, ·65 of an inch; breadth, ·3 of an inch.

This species differs from *Rhymodus transversus* in general form. The depressions on each side of the crown and parallel to the border are not present, and the lateral borders are much less prominent. The presence of the wide ridge parallel to the anterior margin is also characteristic. The surface of enamel in *R. transversus* is punctate; in *R. oblongus* it is longitudinally rugose, and the aliform extensions of the base parallel with coronal surface are much wider in this species than in the former one. The two species agree in the deeply-concave anterior margin, which in this species, as in *R. transversus,* afforded space for the attachment of a secondary portion of the crown.

Genus.—Characodus, Agass. MSS.

Characodus—L. Agassiz, 1859. MSS. Enniskillen Coll.

Palatal teeth, more or less inversely conical in their outline, of medium size; crown, convex; lateral borders produced, forming prominent ridges; coronal surface thickly enamelled, punctate, anteriorly worn by attrition, occasionally considerably incurved over the base and crenated; anterior and posterior margins parallel, straight, slightly convex or slightly concave; lateral margins straight, increasing in diameter backwards; base, comparatively thin, similar in form to that of the crown.

This genus comprises two species, the first of which, *C. angulatus*, must be taken as the generic type. The second, *C. cuneatus,* whilst agreeing in all essential characters, is a considerably longer tooth than *C. angulatus.* Characodus may be allied to the genera Labodus or Rhymodus. To each its transversely oblong form bears a general resemblance; but a closer inspection exhibits peculiarities which clearly separate it from those genera. The crown in Characodus is one-third less in diameter anteriorly than posteriorly, and the base is co-extensive with the crown, whilst the coronal surface of Labodus or Rhymodus is about the same diameter anteriorly as posteriorly; but the osseous base extends in aliform processes on each side, principally towards the back, beyond the lateral margin of the crown, giving to those genera somewhat of the form and appearance of the crown of Characodus.

The genus Characodus may be distinguished from Rhymodus by the absence of the deeply-concave anterior margin, and the crescent-shaped portion of the crown, which is occasionally found occupying the concavity; and from Labodus by its concave or straight posterior margin and prominent base; this margin in Labodus being deeply convex, and extending considerably beyond the basal posterior margin.

Characodus angulatus, Agass. MSS.

(Pl. LVIII., figs. 19, 20.)

Characodus angulatus—L. Agassiz,		1859.	MSS. Enniskillen Coll.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 99.
" "	Enniskillen,	1869.	"Cat. Type Spec." p. 3.
" "	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 349.

Teeth, trapezoidal in outline, medium size, posteriorly about an inch in breadth, half an inch in length; crown, central portion longitudinally and transversely convex. Each lateral border is considerably raised above the central coronal area; surface coated with enamel and deeply punctured; front part of the crown generally worn by attrition; anterior margin two-thirds the breadth of the posterior, straight or slightly convex; lateral margins straight, augmenting in breadth posteriorly; the enamel and the osseous basal portion co-extensive, flat; posterior margin parallel to that of the anterior, straight or slightly concave; postero-lateral angles produced backwards in a line with the side, acuminate, raised prominently forward. Base not well exposed; retreats from the anterior margin of the crown, and extends slightly beyond the posterior one. The tooth is about ·2 of an inch thick.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Characodus cuneatus, Agass. MSS.

(Pl. LVIII., fig. 21.)

Characodus cuneatus—L. Agassiz,		1859.	MSS. Enniskillen Coll.
" "	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 99.
" "	Enniskillen,	1869.	"Cat. Type Spec.," p. 3.
" "	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 349.

Teeth, inversely conical or cuneiform in outline, ·7 of an inch in breadth across the posterior border, diminishing to ·5 of an inch anteriorly. The length of the tooth is ·6 of an inch. Crown, longitudinally deeply convex; the anterior portion more curved than posterior; transversely concave, the lateral borders produced, forming ridges of unequal width; surface enamelled, punctate; two or three broad indistinct plications extend transversely across it; front part hollowed by attrition; anterior margin slightly concave; ganoine infolding base and crenate; antero-lateral angles right angles; lateral margins straight, crenulated, ganoine thick, and infolding to some extent the osseous base; posterior margin slightly convex;

postero-lateral angles obtuse. Base, not well defined; does not appear to be large or thick.

Characodus cuneatus is sufficiently distinct from *C. angulatus*; and, whilst possessing all the generic characters of the latter, its squarer outline, less produced lateral borders of the crown, and the folding of the ganoine over the base on the interior and lateral margins, and its crenated borders, constitute undoubted specific differences.

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Pinacodus, Ag. MSS.

Pinacodus—L. Agassiz, 1859. MSS. Enniskillen Collection.

Palatal teeth, small, more or less cuniformly oblong in outline. Crown, flat or slightly curved. Coronal surface punctate or minutely rugose. Anterior margin, concave. Lateral margins straight or a little convex, diverging posteriorly; posterior margin convex (in *P. gelasimus* concave). Base not well exposed, moderately thick, and co-extensive with the crown.

A second tooth, smaller than the one described, was connected to its anterior extremity, less than one-half the length of the larger tooth; its anterior and posterior margins are convex, the latter closely fitting to the concave margin of the first tooth; surface convex, with raised lateral border, and conforming generally to the shape of the crown of the adjoining one, front portion worn by attrition.

The genus Pinacodus is more closely allied to that of Characodus than any other, and it is perhaps possible that the two genera may at some future time be shown to have only specific differences; the specimens at command do not afford sufficient evidence of this close relationship to justify their amalgamation at the present moment. The crown of Pinacodus is flatter than that of Characodus, and its lateral borders less prominent; the posterior margin is convex in the one, concave in the other, and in Characodus the anterior margin is not hollowed for the accommodation of a second palate, which is perhaps the characteristic of greatest generic importance in Pinacodus.

The form of Pinacodus resembles that of Rhymodus in some respects. The latter possesses a deep sulcus, separating a portion of the anterior face of the tooth, which is probably a second tooth, as with Pinacodus. If this be the case, however, the smaller anterior palate differs very much from that of Pinacodus. It does not appear to have extended the whole breadth of the larger tooth, but becoming laterally acuminate, to have ended before the margin was reached. The basal portions of the tooth of the two genera are quite distinct; that of Pinacodus is comparatively thin, and similar in shape and contour to that of the crown, whilst in Rhymodus the base equals in thickness the length of the coronal surface, and extends considerably beyond its lateral margin on each side.

Pinacodus gonoplax, Agass. MSS.

(Pl. LVIII., fig. 22.)

Pinacodus gonoplax—	L. Agassiz,	1859.	MSS. Enniskillen Coll.
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	Enniskillen,	1869.	"Catal. Type Spec.," p. 7.
" "	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 363.

Teeth, sub-quadrate, slightly conical in outline, ·6 of an inch broad, and ·5 of an inch in length, ·16 of an inch thick. Crown, convex or concave in central part; convex teeth depressed on each side the convexity, the borders raised in all cases to form prominent ridges. Coronal surface punctate or rugose. The anterior margin in the majority of specimens is deeply concave, with antero-lateral angles, rounded to a line with the lateral margin; lateral margin straight or slightly convex; posterior margin convex, upper part forming the angle with the coronal surface constitutes a serrated ridge along the edge of the crown; postero-lateral angles obtuse and rounded. Base not well exposed, but appears to be same form as crown.

In one of the specimens there is a second smaller tooth attached to the anterior margin described above, transversely elongated; it is the same width as the larger tooth, whilst its length is ·15 of an inch only. Its surface is convex, with raised lateral border, conforming generally to that of the adjoining one. The anterior margin of the second tooth is convex; posterior one convex, fitting closely to the concavity of the larger tooth.

The arrangement of the two teeth forming this species affords confirmatory evidence of the identity of the *Copodus lunulatus* with *Copodus cornutus* of Agassiz, as previously stated in these pages. In this instance, as in *Rhymodus transversus*, Ag., the second palate is situated at the front of the larger one, whilst in *Copodus cornutus* the concavity is at the posterior margin of the tooth, and the second palate was situated behind the larger one.

Formation and locality: Carboniferous Limestone, Armagh; rare.
Ex coll. Earl of Enniskillen.

Pinacodus gelasimus, Agass.

(Pl. LVIII., fig. 23.)

Pinacodus gelasimus—	L. Agassiz,	1859.	MSS. Enniskillen Coll.
" "	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" "	Enniskillen,	1869.	"Catal. Type Spec.," p. 7.
" "	J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 363.

Teeth, breadth double the length, posteriorly the breadth is ·6 of an inch, diminishing gradually to the anterior extremity where the breadth is ·4 of an inch, length ·3 of an inch. Crown flat, with a slight convexity at the edges, a circular

depression is worn from the anterior margin to within ·1 of an inch of the posterior one. Coronal surface enamelled, closely and deeply punctate. Anterior margin, concave, lateral ones straight, diverging posteriorly. Posterior margin concave, postero-lateral angles, acute. Base, thin but not well exposed. Unique example.

This species differs from the former in having less prominent lateral coronal borders, flat surface, and in the acuteness of the postero-lateral angles.

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus Dimyleus, Agass. MSS.

Dimyleus—L. Agassiz, 1859. MSS. Enniskillen Collection.

Palatal teeth small, subquadrate; crown, convex; coated thinly with enamel; punctate; transverse sulcus divides the crown into two parts, and probably indicates two teeth. Anterior margin, convex; posterior margin, concave; lateral margins, constricted towards the transverse sulcus, otherwise straight. Base, buried in matrix, extends slightly beyond lateral margin of the coronal surface.

Dimyleus woodii, Agass. MSS.
(Pl. LVIII., fig. 24.)

Dimyleus	woodii—	L. Agassiz,	1859.	MSS. Enniskillen Coll.
„	„	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
„	„	Enniskillen,	1869.	"Catal. Type Specimens," p. 5.
„	„	J. J. Bigsby,	1878.	"Thes. Dev.-Carb.," p. 355.

Teeth, sub-quadrate, small, divided by a transverse depression or suture into two parts. It appears very probable that there are two teeth but the whole of the basal portion being embedded in the matrix, this cannot be satisfactorily ascertained. Crown, convex, thinly coated with enamel, punctured, rather more coarsely towards the border of the crown than in the centre. Anterior margin convex, lateral margin straight, slightly depressed where the suture crosses the face; posterior margin slightly concave; antero- and postero-lateral angles obtuse. A suture-like depression extends transversely across the crown dividing it into two unequal parts, the posterior rather longer than the anterior. Total length ·4 of an inch, breadth ·35 of an inch.

This species received the designation Woodii in recognition and honour of Mr. Wood, late of Richmond, an enthusiastic worker amongst the Limestone fossils of his district, and to whom palæontological science is indebted for many important discoveries.

Formation and locality: Carboniferous Limestone, Richmond, Yorkshire.
Ex coll. Earl of Enniskillen.

Genus.—Mylax, Agass. MSS.

Mylax—L. Agassiz, 1859. MSS. Enniskillen Collection.

Palatal teeth, broader than long. Crown, longitudinally convex; transversely flat, enamelled, rugose or punctate. Anterior margin, concave; posterior margin, convex; lateral ones, convex. Palates succeeded each other on the same plane, the convex posterior margin fitting to the concave anterior one of the tooth preceding it; terminal tooth anteriorly convex. Base strong, with lateral processes extending diagonally beyond the crown.

Mylax batoides, Agass. (MSS.)

(Pl. LVIII., figs. 25, 26.)

Mylax batoides—	L. Agassiz,	1859.	MSS. Enniskillen Collection.
"	"	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
"	"	Enniskillen,	1869.	"Catalogue Type Spec.," p. 6.
"	"	J. J. Bigsby,	1878.	"Thes. Devonico-Carb.," p. 359.

Teeth; breadth ·9 of an inch including basal projections beyond the crown; breadth of single teeth ·15, and of two together ·3 of an inch. Crown divided into two teeth, anterior one ·55 of an inch in breadth, the posterior one ·7 of an inch in breadth: transversely, flat; longitudinally convex along the whole breadth. Surface enamelled, rugose, with intermediate pittings. Anterior margin concave with obtusely rounded antero-lateral angles. Lateral margins convex; posterior margin convex in centre, hollowed towards each side and produced to form acute postero-lateral angles. A suture separating the two palates extends transversely across the specimen parallel with its posterior border, at a distance of ·15 of an inch. Base moderately thick, partially hidden by matrix. Anteriorly and posteriorly it does not appear to extend beyond the crown, laterally, forms aliform processes which extend diagonally ·2 of an inch, at an angle of 45° from the latero-posterior margin of the crown. In a second specimen, smaller than the one already mentioned, the posterior palate is very much less than the anterior one, longitudinally it occupies ·1 of an inch, whilst the one in front of it is ·2 of an inch. The anterior margin in this instance is convex, and the anterior portion of the coronal surface is considerably worn by attrition. It is probable that the convex anterior tooth in this specimen is the terminal one, and that a similar palate originally occupied a position in front of the concave anterior margin of the specimen first described.

The genus Mylax approaches more nearly to those of Dimyleus and Pinacodus than to any others. In Pinacodus, however, the anterior palate is much smaller than the posterior, the reverse of the case with Mylax. The latter is extremely broad in comparison to its length, and the base extends in large processes beyond the lateral margin; in Pinacodus the crown and base are co-extensive, and the tooth

has a quadrate form. The Yorkshire genus, Dimyleus, appears to occupy an intermediate position between those of Pinacodus and Mylax, both in form and structure.

Formation and locality : Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Genus.—Mylacodus, Agass. MSS.

Mylacodus—L. Agassiz, 1859. MSS., Enniskillen Collection.

Palatal teeth, outline subquadrate, medium size. Crown; longitudinally, slightly convex; transversely, central area convex; broad lateral depressions with a slightly raised lateral border. Coronal surface thickly enamelled, punctate or rugose. Anterior and posterior margins convex, lateral ones nearly straight; antero- and postero-lateral angles rounded. Base thick, transversely rounded, deepest in middle, extends to, or a little beyond, the lateral margin of the crown, anteriorly retreats slightly and has a compensating prominence posteriorly.

Mylacodus quadratus., Agass. MSS.

(Pl. LVIII., figs. 27, 28.)

Mylacodus	quadratus—	L. Agassiz,	1859.	MSS., Enniskillen Coll.
,,	,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,,	,,	Enniskillen,	1869.	"Catal. Type Specimens," p. 6.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 359.

Teeth : subquadrate, length ·75 of an inch ; breadth ·7 to ·8 of an inch. Crown more or less horizontal, longitudinally and transversely convex in middle area, with a broad shallow depression on each side, and a slightly raised lateral border. Anterior area generally considerably worn by attrition during mastication. Instances occur in which the whole central part of the crown has been worn away. Coronal surface thickly enamelled, covered with an irregular arrangement of pittings. Anterior margin convex, laterally almost straight, with tendency to convexity; enamelled edge of crown in some instances serrated; posterior margin convex, slightly broader than the anterior one; antero- and postero-lateral angles all obtusely rounded. Base ·3 of an inch thick at the back of the tooth; ·2 of an inch in front; longitudinally straight; transversely rounded, thick in the middle, thinning out towards each side, where the base projects slightly beyond the coronal margin. In front the base retreats from the enamelled surface with a slight concavity. Behind, on the contrary, the base projects slightly beyond the enamelled surface.

This species is tolerably common at Armagh. The specimens vary in size from the one described to palates not more than a quarter of an inch in diameter. They also offer some variation in form. Examples occur in which the tranverse diameter

is greater than the longitudinal; but all approximate, more or less, to a right-angled outline.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Mylacodus sesamini, Agass. MSS.

(Pl. LVIII., fig. 29.)

Pinacodus sesamini, L. Agassiz, 1859. MSS. in the Enniskillen Coll.

" " Enniskillen, 1869. "Cat. Type Specimens," p. 7.

Teeth; length, ·6 of an inch, breadth, ·7 of an inch. Crown, longitudinally convex, worn by attrition on the anterior portion. Transversely, the central part is elevated and flat. A considerable depression extends along each side the central elevation, from which the surface again rises to form rather prominent lateral borders. Coronal surface, enamelled, minutely and uniformly pustulately rugose. The anterior margin is slightly convex, lateral ones having a slight convexity. The posterior margin is deeply convex. All the angles are obtusely rounded; only a single specimen has hitherto been found; the base is hidden by the limestone matrix.

This species may be distingushed from *M. quadratus* by its more cone-shaped form, and the decidedly rugose markings on the coronal surface.

The palate in the collection of the Earl of Enniskillen, named by Prof. Agassiz *Pinacodus sesamini,* differs materially from the type of that genus. Its quadrate form, rounded angles, and the arrangement of the coronal surface, separate it distinctly from the type of the genus Pinacodus. At the same time they indicate, with equal certainty, its relationship to Mylacodus. I have, therefore, placed it in the latter genus, retaining the *nomen triviale, sesamini* of Agassiz to distinguish it from *Mylacodus quadratus,* Agass.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Genus.—Homalodus, Davis.

Palatal teeth; outline more or less quadrate or trapeziform, medium size, thick and strong. Crown flat, lateral extensions unequal; coronal surface enamelled, punctate, or reticulated; anterior margin, convex or straight; lateral margins straight on one side, the other convex; posterior margin more or less sinuous. One of the postero-lateral angles forms a considerable expansion from the coronal surface, terminating in an acute angle. Base thick, slight convexity in medium area of transverse section, concave on each side, longitudinally straight—conforms generally in outline to that of the crown, smooth, fibrous.

The flat, pavement-like coronal surface of this species, combined with its irregular contour, and the one-sided horn-like prolongation of the postero-lateral angle, serve to render its character sufficiently peculiar, and to distinguish this genus from all others.

Homalodus trapeziformis, Davis.

(Pl. LVIII., fig. 30.)

Teeth: trapeziform, large and strong, 1·12 inch in length, anterior margin 1·1 inch in breadth, greatest breadth across the posterior extremity 1·5 inch. Crown: flat, slightly bevelled towards the borders, depression in the left centre worn out by attrition. Coronal surface covered with enamel, minutely and irregularly punctate, the punctures towards the left lateral extension of the tooth gradually disappear and a reticulated arrangement of the enamel takes their place. Anterior extremity, convex; the convexity extends without intermission along the left lateral margin forming a rude semicircle; right lateral border, straight, the angle formed by it with the anterior margin is a right angle. Posterior border, slightly concave. Right postero-lateral angle slightly produced and acute. The left postero-lateral angle is much produced and extends ·35 of an inch beyond the posterior margin, forming with the semicircular extension of the anterior margin an acute angle. Base not exposed.

Formation and locality: Carboniferous Limestone, Armagh. Very rare.
Ex. coll. Earl of Enniskillen.

Homalodus quadratus, Davis.

(Pl. LVIII., fig. 31.)

Teeth: sub-quadrate in outline, length ·8 of an inch, breadth in middle of tooth the same, diminishing slightly anteriorly and increasing about the same amount posteriorly. Crown, flat, with a very slight depression towards the left lateral border. Coronal surface thickly enamelled, uniformly punctate. Anterior margin, straight or very slightly concave. Lateral margin, straight, gradually diverging posteriorly. Antero-lateral angles, obtusely rounded. Posterior margin slightly convex. Left postero-lateral angle produced and acute. The enamel of the crown extends slightly beyond the marginal surface of the basal portion, and constitutes two-fifths of the whole thickness of the tooth. Posteriorly the tooth is ·25 inch in thickness; anteriorly this is diminished to ·17 of an inch. Root, smaller than crown but conforms generally to it in form. Transverse section, slightly convex in centre, concave towards each lateral margin. Longitudinal section straight. Surface, smooth, longitudinally striated.

This species may be distinguished from *Homalodus trapeziformis* by its square form and the much dimininshed size of the left postero-lateral angle. The large development of the left lateral extension of *H. trapeziformis* giving the whole of the anterior and lateral margins a semicircular form, does not occur to nearly so large an extent in *H. quadratus*, though it has similar distinctive features developed in a minor degree.

Formation and locality: Carboniferous Limestone, Armagh. Very rare.
Ex coll. Earl of Enniskillen.

Family : PETALODONTIDÆ, Newberry and Worthen.

The genus Petalodus was instituted by Prof. Owen in 1840 ("Odontography" p. 61, pl. 22, figs. 3, 4, 5,), and considered a sub-genus of Psammodus, the crown of which is produced into a median ridge and compressed, so that the ridge terminates the contour of the crown, like a trenchant edge. In the type specimen from the collection of the late Sir Philip Egerton, the trenchant margin is slightly convex and finely serrated, the crown is invested with a thin layer of dense enamel with a smooth and shining surface, around the base of the crown the enamel is disposed in a series of concentric lines which extend lower down on the posterior than on the anterior surface of the tooth, and the enamel terminates on both sides in a line which is convex towards the base of the tooth, contrary to the terminal contour of the enamel in the compressed teeth of the sharks. The osseous basis of the tooth terminates in an expanded obtuse convex margin. This lamelliform tooth is bent slightly upon itself, so that a vertical section exhibits a slightly sigmoid flexure.

M. Agassiz recognized the genus Petalodus of Owen, and transferred his *Chomalodus acuminatus* to it along with several others (" Poiss. Foss.," Vol. III., p. 174, *footnote,*) which were not described, but which he considered should form a family separated from the Cestraciontes, because of the sharp cutting edge characteristic of the teeth. The species included are the following :—

Petalodus	acuminatus (Chomatodus).	Yorkshire, Glasgow.
,,	hastingsiæ, Owen (type).	Armagh.
,,	psittacinus.	Armagh.
,,	lævissimus.	,,
,,	rectus.	,,
,,	radicans.	,,
,,	marginalis.	,,
,,	sagittatus.	,,

The *Petalodus rectus,* Ag., is figured in the "Geol. Report of Col. Portlock," tab. 14, fig. 9, and in 1854 M'Coy redefined the genus and described and figured the species named by Agassiz as follows :— (" Palæoz. Foss.," p. 635, et seq.)

P. acuminatus, Ag. (+ P. rhombus, M'Coy.)
P. hastingsiæ, Owen (+ P. lævissimus, Ag.)
P. psittacinus, Ag.
P. rectus, Ag. (+ P. marginalis, Ag.)
P. sagittatus, Ag.

The remaining species named by Agassiz was elevated to form the type of a new genus *Polyrhizodus magnus* (=*Petalodus radicans,* Ag.) characterized by the base,

which is simple and homogeneous in Petalodus, being divided into a variable number of distinct root-like lobes or fangs.

During the year 1858 Agassiz revised the Petalodonts in the Florence Court Collection, and in addition to confirming the determination of M'Coy with respect to Polyrhizodus, he raised the species *P. psittacinus*, Ag., to form the type of a genus Petalorhynchus.

In 1866, Messrs. Newberry and Worthen published the following synopsis of Petalodont genera ("Geol. Survey of Illinois," Vol. II., p. 31) :—

Family, Petalodontidæ, Newb. and Worthen.

"Teeth compressed, transversely elongated, crown with anterior and posterior surfaces enamelled, meeting above in a more or less acute-angled edge, bordered below by imbricating folds of enamel, which encircle the crown; anterior crown-face generally convex; posterior concave; root more or less developed, sometimes large, sometimes nearly obsolete, bony, rough, tumid."

The family, Petalodontidæ, as defined by Messrs. Newberry and Worthen, comprises the following genera :—

1. Petalodus—Owen.
   P. hastingsiæ—Owen (type).
2. Petalorhynchus—Agass. (gen. indet.)
   P. sagittatus—Agass. (type, sp. indet.)
3. Ctenophychius—Agass.
   C. serratus—Owen (type).
   C. apicalis (Ag. indet.) (type).
4. Antliodus—Newberry and Worthen.
   A. mucronatus—Newberry and Worthen (type).
5. Dactylodus—Newberry and Worthen.
   D. princeps.—Newberry and Worthen (type).
6. Polyrhizodus—M'Coy.
   P. magnus—M'Coy (type).
7. Chomatodus—Agass.
   C. linearis—Agass. (type).

To the above must be added :—

8. Ctenopetalus (Ag. indet.)—Davis.
   C. serratus (Ag. indet.)—Davis (type).
9. Harpacodus (Ag. indet.)—Davis.
   H. dentatus (Ag. indet.)—Davis (type).

The teeth comprised in the family Petalodontidæ as indicated in the list of genera given by Messrs. Newberry and Worthen, "Geol. Survey of Ill.," Vol. II., page 31, present an extremely varied series, though each possesses the well-marked features which characterize the family. There is in each genus a concavo-convex, more or less sharply pointed petal shaped crown; it may be broader than long as in Chomatodus and several of the others, whilst in Petalorhynchus, though a great variety may be observed in the form of the teeth, the prevailing form is that in which the crown of the tooth is longer than its breadth. The roots of the several genera also present a great variety of forms. In Petalodus and Petalorhynchus the root or base is strong, tumid, and equalling the crown in length, whilst in Antliodus and Chomatodus the root is very small in proportion to the crown. In Polyrhizodus and Dactylodus, the root is divided into a number of radicles. Notwithstanding their general arrangement into the groups already named there is no distinct line dividing the genera from each other, and intermediate forms may be selected which combine some of the characteristics of one genus with those of another and form connecting links which renders it almost impossible to break up the series into well defined genera. Messrs. Newberry and Worthen had a due appreciation of this difficulty, and remark that "if we could have for study the entire organism now so dimly shadowed forth, in these numerous, variable, and disconnected teeth, we should find in the form, in the complete dentition or in other organs—the fins, the spines, the branchial openings, etc., characters by which the group of fishes here represented might be arranged in a large number of well defined genera, the community of form and structure which their teeth exhibit would probably then be shewn to be a family, and not a generic character." *

Having briefly reviewed the classificatory position of the Petalodonts, it is proposed now to consider their relationship to other forms, fossil and recent, and endeavour to deduce their zoological affinities, for this purpose a great help is afforded by the genus Petalorhynchus.

The collection of Lord Enniskillen includes a large and magnificent series of specimens of detached teeth of Petalorhynchus, varying very greatly in form and size, so much so that without so large a series for comparison, it would have been almost impossible to have comprised all the different forms under one specific head. A detailed description of the teeth will be given in succeeding pages, and two or three typical teeth are depicted on Pl. LXI., figs. 12, 13, 14. In addition to the numerous series of detached teeth, there is in the collection referred to, a number of vertical rows or sets of teeth (Pl. LXI., fig. 16), and a single example showing the horizontal or lateral arrangement (Pl. LXI., fig. 15). The latter example consists of the crowns of three teeth, a central or median tooth, and two lateral ones. They are undoubtedly in the same relative position they occupied in the mouth of the living fish; the crown of the central tooth is much longer than the ordinary form,

* "Geol. Survey Illinois, Palæont.," Vol. II., p. 32.

and proportionately narrower; the teeth on each side are shorter, more acuminate at the apex, and broader than the central one.

The vertical sets of teeth (Pl. LXI., figs. 16, 16a) are often in groups of five, occasionally fewer. The smallest tooth is nearest the base, and was the one first used; the crown is about half the length of the tooth, which is half an inch. The second tooth rises beyond it ·2 of an inch, and is ·3 of an inch across the crown. A third and fourth tooth in succession have place before the newest and largest tooth is reached. The breadth of the convex crown of the latter, though not well preserved, was ·7 of an inch, and the total length from its apex to the basal extremity is 1·4 inch. From the base to the apex, the series of teeth present on the anterior face a uniform convexity, as represented in Pl. LXI., fig. 16a, whilst the opposite, or surface inside the mouth is concave, and formed simply of the crown and base of the longest and most prominent tooth, similar to the one represented in Pl. LXI., fig. 14.

The crowns of the lower teeth are circular, or very slightly pointed; the upper one, in use immediately prior to the decease of the fish, is pointed in the centre, and in some instances is very long compared with the breadth, as in the centre tooth. (Pl. LXI., figure 15.) It is probable, from the appearance of abrasion and wear of the enamel along the crest of the crown, and for a little distance down the convex face, that the lower teeth have each in turn occupied the primary position, and having served their purpose have been replaced by new teeth, which have grown or been raised up from the interior of the mouth; the opposite to the method of increase generally observed in Elasmobranch fishes. The apex of the crown of each antecedent tooth is firmly pressed, and appears to become adherent, to the imbricated base of the convex crown of the following one. The small teeth represent an early stage of the fish's existence, and each succeeding one, larger than the last, may indicate a more or less definite period, but certainly prove that as the fish increased in size its dentition, and the consequent extent of the gape of the mouth, also increased.

Having considered the vertical arrangement, there remains the further question as to the lateral or transverse disposition of the teeth. Fortunately, a single specimen occurs in the collection which throws considerable light on this part of the subject. It is a natural inference, from the arrangement of the three crowns, illustrated in Pl. LXI., fig. 15, that the vertical series of teeth occupied a position side by side in a horizontal row; and, judging from comparison with other and existing fishes, it is improbable that the entire series is represented by three teeth, but rather that it was more extensive, and consisted of at least seven teeth. This is rendered probable from the great resemblance existing between Petalorhynchus and the Janassa described by Count Münster, to be further alluded to. Whether seven was the number of teeth occupying each jaw at any given time or some other was the number may be doubtful.

near the basal extremity may have been separated one from the other, so as to give a more expanded disposition to that portion of the teeth; but, that such was the case is at any rate doubtful, because in the young fish, when only the smallest or earliest set of teeth existed, they would extend in close contiguity round the jaw. On the advent of the second set, their larger and broader crowns extended beyond, and above the first, and so enlarged the surface and diameter of the gape. In the same way, the further additions of the third, fourth and fifth rows constantly increased the size of the mouth with the growth of the fish; and it does not seem probable that the earliest teeth changed from their original position relative to each other. It is also worthy of remark, that the majority of the vertical sets exhibit a more or less bilateral arrangement, the lower teeth inclining to the right or left, and having the appearance which would be presented if they had been placed at the side of a central row, being inclined at an angle fitting them to occupy such a position.

The teeth already described are in all probability the primary teeth of the lower jaw. The primary or largest tooth of the central vertical series and the one in use was longest, and proportionately more pointed than those on each side of it. It is probable that the central primary tooth of the upper jaw was longer and narrower than those of the lower jaw, and that the three teeth represented in Pl. LXI., fig. 15, are those of the upper jaw. In this example the length of the crown of the central tooth is greater than one and a half times its breadth. It is pyramidally cone-shaped, and converges to a bluntly-pointed apex. There are imbricating folds across the base of the crown extending in parallel, slightly-curved lines, but not with the peculiar sigmoidal curvature of the lateral teeth. The base is proportionately very long and strong—almost quadrate in section—composed of coarsely-striated osseous tissue. The second, third, fourth, and fifth teeth succeed each other in diminishing sequence, the smallest tooth being nearest the base. Their general character is similar: the concave posterior surface of the crown of the second tooth rests on the convex anterior surface of the one preceding it, and so on. The apex or cutting edge of the crown in the secondary and succeeding teeth is, in almost all cases, circular, and without the pointed apex of the primary teeth. This appears, in all probability, to be due to those teeth having previously served as primaries, and become worn during attrition, the most recent and largest teeth being those in use. In each case the apex of one tooth rests on the imbricated folds of the anterior coronal ridge of the preceding one, and must serve as a substantial support to it. The whole series form a strongly convex mass. So close is the contact between the lower basal portion of the series of teeth that their planes of division appear to have become obsolete, and the whole anchylosed into one solid body. It is difficult to say whether this be really the case; but where a set of the teeth have become fractured, it is almost impossible to trace any division between them.

Whilst searching for affinities or relationship of this peculiar arrangement of

teeth amongst recent or fossil fishes, a striking resemblance in some respects is observed between it and the fossil genus Janassa of Münster—(Beiträge zur Petrefactenkunde, Heft V., p. 38, et seq.) Messrs. Hancock and Atthey have pointed out the identity of Janassa with Climaxodus (M'Coy) in the "Nat. Hist. Trans. of Northumberland and Durham," vol. iii., p. 330. The teeth of both genera are described as generically identical, "the differences being only those of proportion, there being not a single character of importance to distinguish one from the other." "The teeth are depressed and elongated in the antero-posterior direction, and lapse a little backwards. In form there is a wide concave margin, which standing up, like a scoop or dredging bucket, is the cutting edge. Behind this the surface is covered with transverse imbricated ridges, forming the grinding or crushing portion; and further down, on a lower plane, the broad depressed root projects backwards and downwards for a considerable distance. In profile they present a sigmoid curve, the frontal scoop-like portion standing up in the direction of the oral cavity, the posterior or root-extremity being turned downwards in the opposite direction." Both genera are described as possessing two kinds of teeth. "Those already indicated may be looked upon as the principal or primary dental organs; the other kind, or the secondary, in the two genera resemble each other just as closely as do the primary; and it is interesting to find that these secondary teeth agree pretty closely with some of those included in the genus Petalodus of authors, only they are oblique. The association of these Petalodontoid teeth with the primary ones is too obvious to be called in question." In Janassa the two forms are actually found arranged in order, side by side, both in the British and German specimens. The latter are from the magnesian limestone, the former from the coal measures and mountain limestone.

The teeth are described as being arranged in the mouth "in slightly arched transverse rows, the largest symmetrical primary tooth being situated on the median antero-posterior line, and projecting a little in advance of the others, on each side of this there are two similar teeth, but somewhat less, the outside one being twisted obliquely; the row is then terminated on either side by one of the Petalodontoid form. There are therefore seven teeth in each row, including both kinds—five primary, two secondary. Münster represents five or six rows in close succession from back to front, the teeth and rows gradually diminishing in size forward. It is evident, then, that the arrangement of the buccal armature more closely resembles that of the rays than the cestracionts or the sharks; and indeed notwithstanding the difference in the teeth themselves, in their arrangement they agree in a remarkable manner with those in *Myliobatis aquila* and *Zygobatis marginata*—a relationship which was recognized by Agassiz. The largest teeth are $1\frac{3}{8}$ inch in length, including the root, and $\frac{7}{8}$ inch wide at the broadest part. Smaller side teeth are not more than $\frac{6}{8}$ inch long and the petalodont secondary teeth about $\frac{3}{8}$ inch in length. The crown is fully two-thirds the entire length

and is divided into two portions, the anterior one occupies one-third the crown, it is a wide, hollow, arched, scoop-like cutting margin, which in some specimens is obscurely and minutely crenulated or denticulated, and is usually quite sharp, the second posterior part occupies two-thirds the crown, it is shield-formed, somewhat convex, with the point directed backwards and the sides evenly arched outwardly. This portion is traversed by a series of strong transverse undulated ridges imbricated forwards and divided by wide deep grooves, where the ridges are much worn they are smooth, but where fresh they are rough or deeply notched. The root is a wide plate as broad as the tooth and tapers slightly backwards, behind it is rounded, convex above and concave below, and projects backwards on a lower plane, the crown being elevated above its upper surface. The lateral teeth are similar to the above, but they are inequilateral, one side concave the other convex.

A comparison of the teeth of Janassa with those of Petalorhynchus exhibits a great degree of similarity and also many essential particulars of dissimilarity. The two genera agree in the quincunx arrangement of the teeth in the mouth, for notwithstanding the circumstance that no example showing the complete transverse dentition of Petalorhynchus has been discovered, still sufficient is known to prove that the teeth existed in transverse rows, and the probability is that the arrangement of the teeth in the two genera was uniform. That the vertical arrangement was the same in each is amply proved; there is in each a gradual increase in size from before, backwards; the largest teeth being those in use, and the smaller ones serving to support and strengthen them. The process of growth or accumulation must have been the same in both species, each additional row being superimposed from the inside, a method which is almost unknown amongst existing species of sharks or rays. The two genera differ much in detail, however, in the form of the vertical sets of teeth; in Janassa, the group of teeth form a thick mass, five or six teeth being equal in thickness to the length of the longest tooth, whilst in Petalorhynchus the teeth are thinner, and so arranged as to form a closed, dense mass, as firmly attached to each other as if they were anchylosed, and the breadth is less than one-third the length of the largest tooth. The coronal surface of the tooth in the two genera is divided into two parts, a petaliform portion for cutting, and a second imbricated palatal surface, but the relative importance of the parts is very different. The cutting surface of the tooth of Janassa is small and the apex is simply circular, that of Petalorhynchus large, longer than broad, and the central portion of the cutting edge, more or less produced and acuminate; in the latter also the imbricated surface is small or absent and does not appear to have served a very important part in the economy of the fish, and the long root has been deeply embedded in the cartilage of the jaw. The imbricated surface in Janassa is quite different, it occupies two-thirds of the crown or about one-half the entire length of the tooth, and it was in constant use for the

purpose of crushing and masticating the food of the fish. The teeth of Janassa, formed not only a sharp cutting edge, but a large palatal surface extending horizontally backwards along the floor and roof of the mouth. Those of Petalorhynchus differed materially from this arrangement and constituted only a sharp cutting surface; they appear to have been the teeth of a predaceous fish, rather than of one which was a vegetable feeder as Messrs. Hancock and Atthey argue that Janassa was.

Prof. Agassiz, who described and figured the Janassa of Münster as *Acrodus larva* ("Pois. Foss.," Vol. III., p. 147, tab. 22, figs. 23-25), but afterwards recognised its proper position and affinities ("Op. Cit.," p. 376), considered that Janassa was an intermediate type between Myliobates and the Cestraciontes, and contributed to bridge over the gap between the rays and sharks, the limits of which appear always less sharp in proportion as they become better known. Prof. Agassiz also points out certain analogies between Janassa and Zygobates and Rhinoptera.

The dentition of the genera Myliobates and Zygobates possess several characters in common. In place of pointed teeth they possess a series of dental plates, which form a pavement-like covering attached to each upper and lower jaw: the teeth are attached to each other by sutures, and extend in rows of seven teeth each, from the front of the mouth far backwards towards the gullet. The chief peculiarity of these teeth lies in the large development of the central plate, which extends across the symphysis of each jaw; it is larger in Myliobates than all the remaining six teeth together. The latter are arranged three on each lateral extremity of the central one. The central teeth of Zygobates are proportionately not so large as those of Myliobates, the side teeth diminishing in size as they recede from the central one. Both genera are represented by a few existing fishes but are found fossil in large numbers amongst the Tertiary rocks. The teeth of Janassa and Petalorhynchus are similar to, and agree with those of Myliobates and Zygobates in the arrangement of the teeth in transverse rows, and in the position of the central or medium tooth which covers the symphysis of the jaw: a peculiarity which does not ordinarily obtain in the dentition of fishes, the teeth usually occupying positions on, or in each ramus of the jaw but not extending across, or otherwise connecting, the two rami. The latter feature, especially considering its rarity, is remarkable, and it was from its occurrence in Janassa that Prof. Agassiz derived the idea that the genus possessed affinities with the rays How far he may be correct has not yet been demonstrated. The broad, ridged teeth of Janassa with short horizontal crowns, adapted both for cutting and crushing its food, bear a greater resemblance to the flat pavement teeth of Myliobates, adapted only as a crushing or triturating surface, than do those of Petalorhynchus. The teeth of the latter are pre-eminently cutting teeth, and though a number of imbricated folds or ridges usually extend across them, it is not probable that they were of the least service for masticatory purposes, the teeth

being in a position too nearly perpendicular to render the ridged surface available. The teeth in both genera resemble each other much more than either resembles Myliobates, and except in the fact of the central tooth in each extending across the median division of the jaws, there could be little claim of relationship between the sharp, pointed, cutting teeth of the one, and the flat, extended plates of the other. In Myliobates and Zygobates each transverse row is composed of seven teeth, a largely expanded median tooth with three angular-sided flat-surfaced teeth on each side—a number which corresponds with that of Janassa, and in all probability with that of Petalorhynchus.

From a careful consideration of all the external characteristics of Petalorhynchus and comparison with those of Petalodus the conclusion must be reached, that they possess generic features in common, and that whatever may ultimately be proved to be the zoological position of one of them, will, in all probability, be found to include the other. Whether this relationship will be found to extend also to the varied genera which are included by Messrs. Newberry and Worthen in their definition of the Family Petalodontidæ may be doubtful. The genus Janassa (including Climaxodus, M'Coy) which has been shown to possess characters closely associating it with that of Petalorhynchus, will also be found to form one of the same family. This appears to have been to some extent foreseen by Messrs. Hancock and Atthey, who state that* "Ultimately, perhaps, Petalodus will be found to be more closely related than can at present be demonstrated (*i.e.*, to Janassa), for it is not only in the Petalodontoid form that a resemblance is observed, but likewise in the primary teeth themselves, which show a remarkable similarity in general form to some of the Petalodontes." And in a second paper "On *Janassa bituminosa*, Schlotheim, from the marl slate of Durham"† by Messrs. Hancock and Howse, the concluding paragraphs are, "It is unnecessary here to dilate on the affinities of Janassa. We may remark, however, that the full investigation of the Permian Species has only the more confirmed our opinion of its close alliance with the coal measure form (the so-called *Climaxodus linguæformis*), and of a certain relationship of both to Myliobates and Zygobates. We may also state that Janassa is more closely related to Petalodus than was at first thought; for we now find that the latter genus is provided with both symmetrical and oblique teeth; so that it is quite probable that they may be found to be arranged in much the same manner as those of Janassa, especially as the former have been found in vertical series, as previously stated."

It thus appears that a close relationship exists between Petalodus of the Mountain Limestone, Petalorhynchus of the Yoredale Rocks, Climaxodus from the Coal Measures, and Janassa from the Permian Rocks, and that the latter, whilst agreeing in the main with the genera of the older formations, also possess some

* "Op. Cit.," p. 335. † "Op. Cit.," p. 356.

characters which appear to ally them with the more recent genera Myliobates and Zygobates of the Tertiary formations, whose representatives still exist, principally inhabiting tropical seas. The fossil remains of the several genera are so fragmentary, that it is extremely difficult to obtain sufficient data whereon to base deductions of so great import as those above indicated. Of the older genera Petalodus and Petalorhynchus absolutely nothing has been found except the teeth; and those only, except in very rare instances, as detached specimens. Along with the teeth of Climaxodus and Janassa, masses of minute tuberculous shagreen have been found associated. In a variety of the latter genus, described by Münster as *Dictea striata* (Beiträge zur Petrefactenkunde, tome iii., tabs. 3 and 4, fig. 1), the form of the whole body is indicated and is completely covered with fine shagreen. The length of the fish is 0·390 metre, exclusive of the tail, the greatest breadth is 0·110 metre between the pectoral and ventral fins, the height of the head is 0·080 metre. The specimens obtained from the Marl Slates of Durham have also associated with them masses of shagreen, and from the arrangement of the teeth, it is inferred that the mouth was underneath the head as in the Elasmobranchi. They possess an anal fin. The more recent genera Myliobates and Zygobates are well known from their living representatives. The dentition forms a perfectly flat mosaic-like pavement. The body is widely expanded, short, and comparatively thin, and does not possess anal fins. It is more or less covered with tuberculated shagreen. Occasionally a serrated spine exists in connexion with the dorsal fin.

The gradual change in the form of the teeth; from the deeply-rooted, strong sharp cutting teeth of Petalodus through various modifications in intermediate genera to those of Janassa which combine the sharp cutting edge with a large expansion of the base of the crown in the form of imbricated folds, adapted to crushing alimentary substances, may have developed still further to form the altogether flat teeth of the Myliobate rays, in which the cutting teeth have entirely disappeared. The internal framework of all the fossil genera was composed of cartilage and has entirely disappeared.

Genus.—Petalodus. Owen.

Ref. R. Owen, 1840. "Odontography," p. 61.

"Teeth transversely elongated, much compressed, thin, petal-shaped, cutting edge serrated; base of crown with several narrow imbricating folds of enamel, descending lower on the posterior than the anterior face; root large, oblong, thin, truncated below; lower edge, obtuse, tumid."

Petalodus hastingsiæ, Owen.

(Pl. LIX., figs. 16–21.)

Petalodus Hastingsiæ—	R. Owen,	1840.	"Odontography," p. 61, pl. xxii., figs. 3, 4, 5.
„ „	L. Agassiz,	1840.	"Rech. sur les Poiss. Foss.," Vol. III., pp. 174 and 384.
„ lævissimus,	„	1840.	"Rech. sur les Poiss. Foss.," Vol. III., pp. 174 and 384.
„ Hastingsii—	J. E. Portlock,	1843.	"Geol. of Londonderry," &c., p. 468, pl. xiv., fig. 10.
„ lævissimus,	„	1843.	"Geol. of Londonderry," &c., p. 461.
„ Hastingsiæ—	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
„ lævissimus,	„	1848.	„ „ „ Vol. I., pt. 3, p. 345.
„ „	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 949.
„ Hastingsiæ,	„	1848.	„ „ p. 949.
„ „	J. Morris,	1854.	"Catal. Brit. Foss.," p. 337.
„ lævissimus—	„	1854.	„ „ „ p. 337.
„ „	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 271.
„ Hastingsiæ,	„	1854.	„ „ „ Vol. II., p. 271.
„ Hastingsii—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 635.
„ Hastingsiæ—	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc." Vol. XVIII., p. 101.
„ lævissimus—	„ „	1862.	„ „ „ „ Vol. XVIII., p. 101.
„ „	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glas.," Vol. III., Supplt., p. 74.
„ Hastingsiæ—	W. H. Baily,	1875.	"Figs. of Char. Br. Fossils," p. 120, pl. xli., fig. 11.
„ lævissimus—	Armstrong, Young, and Robertson,	1876.	"Catal. of W. Scot. Foss.," p. 62.
„ Hastingsiæ—	J. J. Bigsby,	1878.	"Thesaurus, Dev.-Carb.," p. 361.
„ lævissimus,	„	1878.	„ „ „ p. 361
„ „	De Koninck,	1878.	"Fauna du Calc. Carb. de la Belgique.," p. 50, pl. vi., figs. 6, 7, 8.

Teeth, "crown very thin, scale-like, gently convex along the upper edge, turning abruptly downwards at the extremities; base of the crown with a broad series of five or six imbricating folds of ganoine, towards which the crown slopes without convexity downwards and outwards so that they form the thickest and most prominent part of the tooth; they are arched downwards in the middle, but abruptly curved upwards, and downwards again at the lateral fourth of the lengths; root abruptly narrowed, flattened, tongue-shaped, one third deeper than the crown on the outer side; surface highly polished, and smooth when perfect, the cutting edge alone being marked with a row of punctures; when worn, however, a fine line extends from each of these punctures half-way down the crown, producing a striation scarcely visible to the naked eye."—(*M'Coy*). Average width of the crown ·5 of an inch, height of tooth about the same as width of crown, of which the crown occupies two-fifths.

Specimens in the collections of Lord Enniskillen and others bear the *nomen*

riviale, P. lævissimus, given by Prof. Agassiz to teeth of Petalodus which he at one time considered distinct from *P. hastingsiæ,* further observation, however, convinced that learned ichthyologist that they were modifications only of the same species.

The teeth vary considerably in detail as to form, and occasionally examples are discovered which appear to be considerably distorted, as in Pl. LIX., figs. 18, 20, in which the root is deflected entirely to one side. These examples may have occupied a position towards the posterior extremity of the jaw.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Petalodus acuminatus, Agassiz.

(Pl. LIX., figs. 22–24.)

Chomatodus acuminatus—		L. Agassiz,	1833.	"Rech. sur les Poiss. Foss.," Vol. III., p. 108, pl. lxix., figs. 11, 12, 13.
Petalodus acuminatus—		,,	1840.	"Rech. sur les Poiss. Foss." Vol. III., pp. 174 and 384.
,,	,,	J. E. Portlock,	1843.	"Geol. of Londonderry," p. 461.
,,	,,	C. G. Giebel,	1843.	"Fauna der Vorwelt," Vol. I., pt. iii., p. 345.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 949.
,,	rhombus—	F. M'Coy,	1848.	"Ann. and Mag. of Nat. Hist.," 2nd ser., Vol. II., p. 125.
,,	acuminatus—	H. G. Bronn,	1849.	"Enumerator Palæont.," p. 646.
,,	,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 337.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 271.
,,	,,	F. M'Coy,	1855.	"Brit. Palæozoic. Foss.," p. 635, pl. iii. G, fig. 4.
,,	rhombus,	,,	1855.	,, ,, ,, p. 635.
,,	acuminatus—	Morris and Roberts,	1862.	"Quart. Jour. Geol. Soc.," Vol. XVIII., p. 101.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 361.

Teeth, "Crown sharp, compressed, anterior face of variable height, regularly rhombic, the upper and lower margins sometimes symmetrical, the lateral portions of each being nearly straight, or slightly arched downwards, and meeting in the middle at an obtuse angle, or, more frequently, the angle both of the apex and coronal ridge more or less rounded. The cutting edge is obscurely undulato-dentate in some specimens by short obsolete vertical furrows, and minutely crenulato-striated, more commonly without the vertical plicæ, from the faint undulations of the edges. The lower margin is prominent, and surrounded by five or six small imbrications of ganoine. These descend lower (as usual) on the posterior face, where also the mesial angulation is less; surface smooth, with a few fine irregular longitudinal striæ; root moderately large." Height of the middle of the crown ·9 of an inch; width of crown 1·5 inch; depth of root 1·2 inch. The proportional height and size of the crown compared with that of the root is very variable.

The specimens figured are from the collection of the Earl of Enniskillen and the Reed collection at York. In each case they have been obtained from the same locality, near Richmond, in Yorkshire.

The fine specimen, represented on Pl. LIX., fig. 22, exhibits a peculiar form of the root, which is deeply grooved in a longitudinal direction, and appears to approach, in some degree, to the divided root of Polyrhizodus. In the same specimen the folds which encircle the base of the crown are united, and form a single prominent overlapping plication.

Formation and locality: Mountain Limestone.

Ex coll. Earl of Enniskillen, and Reed Collection, York Museum.

Petalodus rectus, Agass.

(Pl. LX., fig. 5.)

Petalodus rectus—		L. Agassiz,	1840.	"Rech. sur les Poiss. Foss.," Vol. III., pp. 174 and 384.
,,	,,	J. E. Portlock,	1843.	"Geol. of Londonderry," &c., p. 461, pl. xiv., fig. 9.
,,	,,	C. G. Giebel,	1843.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 949.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 646.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 337.
,,	,,	F. J. Pictet,	1854.	"Traité de Palèont.," Vol. II., p. 271.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 636.
,,	,,	Young & Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., Supt., p. 74.
,,	,,	Armstrong, Young, and Robertson,	1876.	"Cat. of W. Scot. Foss.," p. 62.

Teeth: "Very broad, greatly flattened; crown thin, rectilinear, or nearly so; in some specimens slightly undulated, and marked with vertical striæ near the edge, in others, crown surrounded by a broad band of four or five imbricating lamellæ of ganoine; root deeper than the crown and coronal folds together, concave in its upper half, tumid and longitudinally rugged below. Average length of a rather small specimen 1 inch; height of crown 1 line, width of coronal bands $\frac{3}{4}$ line, depth of root $2\frac{1}{2}$ lines. The width and slight elevation of the knife-like crown of this species easily distinguish it from any others. The name of *P. rectus* of Agassiz's published lists applies to the perfect, nearly straight-edged specimens, while his name *P. marginalis* applies to the slightly-worn examples, in which the edge is striated and undulated, and I have traced the perfect passage of one form to the other."—(*M'Coy.*)

This species is figured by J. E. Portlock, in the "Geological Report of Londonderry," &c., pl. xiv., fig. 9. It approaches very nearly in form to the genus Chomatodus, as defined by Messrs. Newberry and Worthen ("Palæont., Illinois," Vol. II., p. 34), excepting the root, which is well developed, and petalodont in character.

Formation and locality: Carboniferous Limestone, Lowick.

Petalodus grandis, Davis.

(Pl. LX., fig. 1.)

Tooth, this is in several respects the largest and strongest member of the group. It is 2·5 inches across the crown. The depth along the central axis of the tooth from the tip of the crown to that of the base is 2 inches. The centre of the coronal surface is highly convex; on each side the convexity gives place to a proportionately deep concavity, the lateral tips of the crown are again raised and stand prominently forward. The convexity and concavity of the surface are reproduced in the crest and anterior margin ·8 of an inch apart, bounding the coronal surface, and give to them sinuous outlines which converge to form a pointed extremity on each side. The junction of the anterior and posterior surfaces of the crown form a crest at an acute angle, with an undulating outline independently of the sinuous one already mentioned. The surface of the crown, where not worn or broken, is covered with enamel, pitted near the basal portion, and, in its higher part, striated and ductiferous. Where the internal portion is exposed by a broken surface, the bony structure with innumerable canaliculi is easily distinguishable. The anterior median ridge is broad, prominent, smooth, and devoid of inferior foldings; as already observed it follows the sinuous outline of the surface of the tooth. Beneath the ridge the anterior surface of the root gradually retreats and becomes, in conjunction with the posterior surface, somewhat thin and acuminate, from the lateral extremities the base of the tooth becomes gradually contracted and terminates in a widely rounded extremity. The base or root is simple and undivided. Its surface near the anterior ridge is longitudinally furrowed, but the furrows disappear lower down. and the base becomes even and smooth, thickest in the middle and thinning off on each side, and forming an acute angle with the opposite surface. The anterior face of a second specimen is exhibited. The antero-coronal ridge is produced in front retreating on each side and much depressed at each lateral extremity, the surface is generally convex, the posterior border evenly circular. The centre of the crown is worn in front. From the anterior ridge the basal portion retreats slightly, forming an unbroken root.

This magnificent specimen bears a close relationship to the species of the genus Polyrhizodus found in the same locality; in every respect except the division of the base into several rootlets, the characters of the two genera are similar. The largest species of Petalodus hitherto described is *P. destructor* N. and W. ("Geol. Ill.," Vol. II, p. 35., pl. ii., figs. 1, 2), from the coal measure limestones of Illinois; it is smaller in size than the species now described, considerably longer in proportion to the breadth, and both the crown and lower portion of the base are much more acuminate than in *Petalodus grandis.*

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Petalodus recurvus, Davis.

(Pl. LX., fig. 2.)

Teeth, medium size. Crown, very broad, nearly twice the breadth of the base as well as of its length; anterior face, laterally circular, vertically concave; apex, circular, minutely serrated, sharp; coronal ridge prominent, with two or perhaps three somewhat indistinctly imbricated folds of ganoine. The width of the crown is 1·4 inch, greatest height in centre ·35 of an inch; from the centre, the coronal ridge by a sigmoidal curvature, approaches towards the apical circumference, the lateral extremities are curved considerably towards the base and end in an acute point. Posterior surface not visible, embedded in matrix. Root, rapidly contracted from the width of the crown to one half its diameter, it is ·4 inch in length, roughly fibrous, convex, laterally depressed.

This species is marked with considerable distinctness from any other British species, neither does it approach near to any of the American forms. It differs from *P. acuminatus,* Agass., in its greater breadth of coronal surface compared with its depth, the roundness of the cutting edge, which in *P. acuminatus* is pointed in the centre. The crown is also much less pointedly produced along the anterior median ridge. The root is shorter, thicker, and has a circular termination.

In general form this species is similar to *P. linguifer* N. and W. ("Palæon. Illinois," Vol. II., p. 37, pl. ii., figs. 4, 5), but may be easily distinguished by the lateral extremities of the crown, which in this species are curved towards the basal portion and acuminate, whilst in *P. linguifer* they are rounded and terminate without curvature towards the base.

Formation and locality: Mountain Limestone, Bristol.
Ex coll. Earl of Enniskillen.

Petalodus inequilateralis, Davis.

(Pl. LX., figs. 3, 4.)

Teeth, length 1·2 inch, height ·55 inch; coronal surface, broad and short, indefinitely sinuous. Base nearly as wide as crown and twice its depth. Crown, anterior surface, expanded on one side the median line to twice the height of the opposite one. The wider half terminates in a rounded extremity without depression, whilst the narrow one is curved towards the base and terminates acutely. Cutting edge, generally much worn or minutely serrated. Coronal ridge somewhat prominent, bearing three or four imbricated ganoine folds, extending across the tooth with a doubly sigmoidal curvature. Posterior surface, deeper than the anterior, but taken up in great part by eight or ten foldings of the surface, so that the smooth portion is less in vertical extent than that of the anterior surface. The form of the posterior portion of the crown conforms generally to that of the anterior one, at the broad end its height is ·35 inch, at the narrow one

it is only ·2 inch, the imbricated folds occupy nearly three-fourths of its surface. Anteriorly the crown is covered with a coat of dense enamel, through which the dentigerous tubes do not appear to penetrate unless it be at the apex, along the serrated edge they may be distinctly seen where the serrations are worn off. Root, anterior surface, from the ridge is depressed and concave, lower portion convex roughly fibrous, posteriorly it is convex and rounded with a number of vertical ridge-like prominences. The root conforms to the general shape of the crown, it is deepest on that side on which the crown is highest, and in the opposite direction gradually converges and meets the coronal surface, forming a slightly acutely-pointed termination.

This species of Petalodus is different in general characters to any other known from the limestone strata of Great Britain. In breadth of the crown and small vertical extent it somewhat resembles *Petalodus rectus*, Agass., but in the unequal development of the two sides of the teeth and the number of imbricated folds separating the crown from the base, it is quite distinct. It might be considered that this peculiar form of tooth was due to its position as a side tooth in connexion with other species of more regular form, were it not that it is confined to one locality in the upper strata of the Limestone series of Yorkshire, whilst in the districts in which the ordinary form of Petalodus is found *P. inequilateralis* is absent, so that it is improbable that such can be the case.

In some respects this species appears to occupy an intermediate position between Petalodus and Chomatodus; its thin sharp crown with serrated apex allies it to Petalodus, whilst its great proportionate breadth and wide extent of surface occupied by the coronal foldings resemble Chomatodus. The root is, however, much more largely developed, more tumid and rounded than in Chomatodus.

Formation and locality: Limestone, Wensleydale, Yorkshire.
Ex coll. Earl of Enniskillen.

Genus.—Petalodopsis, Davis.

Teeth, medium size, strong. Crown, laterally strongly arched, smooth, acuminate. Crest constitutes a sharp cutting edge, divided into three similar denticles; centre one largest, with a deep sulcus on each side separating it from the two lateral ones. Crown separated from root by a coronal band consisting of four or five imbricating folds of ganoine, straight in the middle, bending downwards on each side. Root descends from crown, as in Petalodonts; strong, tapering downwards, inbevelled; not so wide or deep as crown.

The affinities of this genus appear to be with the Petalodonts; the sharp cutting edge of the tooth, and the well developed base or root, are clearly related to that group. It appears to hold an intermediate position between Petalodus and Petalorhynchus; it is separated from the former by its tricuspidate crown, and from the latter by the smallness of the root, absence of palate and paucity of denticles.

Petalodopsis tripartitis, Davis.

(Pl. LX., figs. 6, 6a.)

The genus is represented by this single species, whose characters are those already attributed to the genus. The tooth is ·5 of an inch across, and about the same in height. The crown is ·35 of an inch high in the centre; the central cone, or denticle, is considerably more prominent than the lateral ones, which gives to the tooth an acuminate form. The cutting edge of the outer denticles is slightly serrated, and a number of minute striations descend from the crest vertically over the crown, but disappear, and give place to a smooth, very finely punctate, enamelled surface.

Formation and locality: Carboniferous Limestone, Wensleydale.

Ex coll. William Horne, Esq.

Genus.—Polyrhizodus, M'Coy.

Teeth, strong, transversely elongated. Crown, convex, obliquely elevated, more or less oval in outline, and laterally acuminate; posterior surface of crown, concave, larger than anterior. Crown separated from base by anterior and posterior ridges, with or without imbricating folds; base or root large, deeply implanted, oblong, divided into distinct more or less tuberous rootlets or radicles.

This genus is probably more nearly allied with the Petalodonts than with any other group; and it was, no doubt, this external resemblance, combined with, perhaps, imperfect specimens, that led Prof. Agassiz, in the year 1840 ("Poissons Fossiles," tome iii., p. 174), to ascribe these teeth to the genus Petalodus (*P. radicans*). Specimens were so named in the collection of Lord Enniskillen and others, but, like many other genera and species, were left for description to a future supplement, which, unfortunately, has not been written. In a revision of the fishes of the palæozoic rocks, Prof. M'Coy ("Annals Nat. History," Second Series, Vol. ii., p. 125, 1848) published a description of the genus, for which he instituted the name Polyrhizodus. The description was considerably enlarged upon, and specimens of two species were figured by Prof. M'Coy in his "Systematic description of the British Palæozoic Fossils in the Geological Museum of the University of Cambridge," page 641, pl. 3 k, figs. 2, 6, 7, and 8. The *Petalodus radicans*, Ag., is described under the name *Polyrhizodus magnus.* The second species, *P. pusillus,* does not appear to be a Polyrhizodus, but probably belongs to the genus Helodus. The figures of *Helodus turgidus,* Ag., in the "Poissons Fossiles" do not represent the root or base of the tooth as being divided into fangs or lobes, though one of the figures indicates it to some extent; but in the Enniskillen collection, amongst an extensive range of the *H. turgidus,* examples may be selected which show the division of the root even to a larger extent than the specimen figured.

During the Geological Survey of Illinois a number of fish remains were discovered in the Carboniferous Limestone Series at Burlington and Chester, and amongst

many others are several species of the genus Polyrhizodus. They are described by Messrs. Newberry and Worthen in the Second Volume of the "Geological Survey of Illinois," published in 1866. The genus Polyrhizodus is somewhat restricted by the authors to teeth like the British species, *P. elongatus*, shortly to be described—that is, to examples having a much longer lateral than vertical axis, with the crown of the tooth transversely low, and the root divided into numerous short, robust radicles. In addition, a second genus, Dactylodus, is originated, which includes specimens having essentially the same characters as those ascribed to Polyrhizodus, except that the tooth is relatively longer vertically than laterally, the crown oval, and the rootlets fewer in number (generally four or six), longer, and more robust.

A careful study of the numerous specimens from the mountain limestone of Armagh leads to the conviction that no arbitrary line of the kind indicated in the separation of these teeth into two genera can be maintained. The species described in the following pages appear to be based on good reliable grounds, and are types of considerable numbers of specimens in each case. Some have the elongated form of the Polyrhizodus type of Messrs. Newberry and Worthen, whilst others pertain equally to that of Dactylodus. The occurrence of intermediate forms, however, bridges over the two genera and unites them; or, if such be not the case, it will be necessary to create other genera for the accommodation of each separate form. It is probable that Messrs. Newberry and Worthen may have foreseen this generic identity; for in the fourth volume of "Survey of Illinois" (1870), after describing a new species of Polyrhizodus (*P. truncatus*), they remark :—"A compa rison with the species we have named *P. inflexus* and *P. porosus* (Vol. II., pp. 48, 49, pl. ii., figs. 8 and 9), will show that they should be placed in one generic group with that now under consideration. From those species it is distinguished by its outline, lower and broader than in *P. inflexus*, less low and broad than in *P. porosus*, and by a root more nearly obsolete than in either." The *Polyrhizodus inflexus* here referred to is described as *Dactylodus inflexus*, whilst the *P. porosus* is described as a Polyrhizodus.

Polyrhizodus radicans, Agass.

(Pl. LX., figs. 7, 8.)

Petalodus radicans—	L. Agassiz,	1840.	"Rech. sur les Poiss. Foss.," Vol. III., p. 174 and 384.
,, ,,	C. G. Giebel,	1843.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 949.
Polyrhizodus magnus—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd Ser., Vol. II., p. 126.
Petalodus radicans—	H. G. Bronn,	1849.	"Enumerator Palæont.," p. 646.
,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 337.
Polyrhizodus ,,	,,	1854.	,, ,, ,, p. 340.
,, (magnus)	,,	1854.	,, ,, ,, p. 340.
, ,,	F. J. Pictet,	1854.	"Traité de Palèont.," Vol. II., p. 271.
(Petalodus radicans)	,,	1854.	,, ,, ,, p. 271

Polyrhizodus magnus—F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 641, pl. 3 k., figs. 6, 7, 8.
" radicans—Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
" " Enniskillen,	1869.	"Cat. of Type Spec. Foss. Fishes," p. 7.
" " Young & Armstrong,	1871.	"Trans. Geol. Soc., of Glasgow," Vol. III., Supt., p. 76.
" " Armstrong, Young, and Robertson,	1876.	"Catal. West. Scot. Foss.," p. 63.
" " J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 363.
" (magnus) "	1878.	" " " p. 363.

Teeth, when full grown 2·5 in. in breadth and 1·5 in. in height. The crown anteriorly occupies one-third of the vertical diameter. From the anterior ridge it inclines at an angle of 45° backwards and upwards to the crest formed with the posterior surface. The anterior coronal surface is smooth, slightly polished, and convex; it is ·75 of an inch across the centre, from which the crest and anterior ridge converge towards each lateral extremity, and terminate in an acute angle. From the raised surface forming the centre of the tooth it is depressed laterally, and towards each end is considerably bent downwards and backwards, so as to combine to form the posterior median ridge. The anterior ridge dividing the crown from the root is plain, and without folds or striæ; beneath the ridge the surface of the tooth retreats almost at a right angle to the crown, with slight vertical plications towards the base of the radicles. Posterior surface of the crown 1·0 inch across the central portion; vertically the section is concave; but laterally the surface forms a nearly-straight line. It is ovoid in form, converging laterally to an acute angle. Lower surface bounded by the posterior ridge ·2 of an inch wide, and consisting of three or four imbricating parallel folds. The ridge is considerably elevated, and a deep groove extends beneath it and the base of the root.

Root, thicker than the upper part, its depth equalling one-third that of the entire tooth. It is divided into twelve or fourteen thin plate-like radicles, deeply cleft and usually separated by an indentation equal to their own diameter. There are generally instances in each tooth in which two of the rootlets have coalesced and form one thick, almost square fang.

Prof. M'Coy has described and figured this species in his work on "British Palæozoic Fossils." The specimens at his disposal appear to have been smaller than those now figured from the cabinet of the Earl of Enniskillen, but otherwise the types agree. A slight discrepancy between M'Coy's description and the plate occurs. In the text it is stated that the number of rootlets is six or eight, whilst in the figure thirteen are represented. The latter is, no doubt, the correct number.

A considerable variety in the details may be observed in the large series of this species collected from the Limestones of Armagh, and at present in the Enniskillen collection. Full-grown teeth are generally more or less worn on the surface, especially in the centre, considerable variety exists in the form of the teeth, in the thickness and the relative size of the crown and the base. The specimens vary in

size very much, and range from the large size of the specimen figured down to about an inch in diameter, the latter, no doubt, being the teeth of younger fishes.

Nothing definite is known as to the arrangement of the teeth in the mouth. Hitherto no specimens have been found which exhibited the relationship or relative position of the teeth to each other. It is probable, however, judging from the worn surface of the central portion of the tooth, that those of the lower and upper jaws formed a corresponding cutting and triturating surface the one to the other, but whether they existed in a simple double row extending backwards along the palate and corresponding to the two rami of each jaw, as might be inferred from the sinuosity of the coronal surface of P. *sinuosus*, Davis. (*vide* page 504), or they were arranged in concentric rows as in some of the large sharks at present existing, there is no evidence to prove. In either case the strong, deeply-implanted, many-barbed root indicates considerable power as well as voracity, especially if compared with the somewhat weak and meagre attachment of the teeth in modern sharks.

Locality: Comparatively abundant in the Carboniferous Limestone of Armagh.

Ex. coll. Earl of Enniskillen.

Polyrhizodus colei, Davis.

(Pl. LX., figs. 9, 10.)

Teeth, breadth across the crown 2 inches, height from tip of root to summit of the crown 1·5 inch. Anterior surface of the crown large, convex, oval in form with depressed lateral prolongations, extending considerably beyond the extension of the root. The centre of the crown is ·9 of an inch from the anterior ridge to its summit. It is much worn, the portion of the surface most constantly used being distinctly indicated by its appearance. The inclination of the surface of the crown to the posterior ridge is about 60°. The surface is smooth and beautifully polished, it possesses almost a transparent appearance, and the ramification of the nutrient vessels is well defined. The lateral portions of the surface which are not worn to any great extent do not exhibit this peculiarity, but are covered with minute punctures. The anterior ridge is doubly curved, upwards from each lateral extremity and downwards to the middle portion of the crown; it is smooth and partakes of the general characters of the crown. The posterior surface of the crown is deeper than the anterior: it is concave and bounded on its lower margin by a high ridge which appears to have consisted of a single fold produced from the body of the tooth. The root at its base is 1·5 inch across; towards its extremity it spreads out to 1·6 inch. It is divided into six (or occasionally seven) large club-shaped rounded rootlets, which retreat from the posterior, and bend forward towards the anterior face of the tooth. The radicles are separated by an interspace one-half their own diameter between each.

I take the liberty of appending the *nomen triviale, Colei,* to this beautiful species in appreciative acknowledgement of the indebtedness of all students of Ichthyology to the bearer of that name, the Earl of Enniskillen.

This species bears some resemblance to the tooth figured as *Dactylodus princeps,* N. and W. ("Palæon. of Illinois," Vol. II., p. 45, pl. iii., fig. 6). The latter is deeper and narrower, whilst the fangs are very long, on the anterior face the roots occupies seven-tenths of the entire height of the tooth.

From all the British species *P. colei* is quite distinct and separate; from *P. radicans* it is distinguished by its greater height, broad crown, narrower space occupied by the roots as compared with the breadth of the crown, and the fewer, more robust, and rotund rootlets. The only other species to which it approaches is *P. sinuosus* whose characteristics can scarcely be mistaken.

Locality: Carboniferous Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Polyrhizodus elongatus, Davis.

(Pl. LX., figs. 16, 16*a*, 16*b*.)

Teeth, length 2·75 inches, height 1·2 inch. The general outline of this species is much broader in proportion to its height than *P. radicans,* but not so contracted as *P. attenuatus.* The coronal surface is barely ·5 of an inch in greatest breadth, which is maintained along two-thirds of its length; at each end it tapers rapidly to a point, much depressed. The surface is slightly convex, covered with ganoine, and where not worn, slightly punctate. The anterior median ridge is separated from the crown by a considerable depression forming a long groove: the ridge is composed of a strong single fold of ganoine, more deeply punctate than the crown, and extending in a nearly straight line across the tooth, near the lateral extremities it is bent downwards diagonally forming the end of the tooth and continued along the posterior surface. The posterior surface of the crown occupies a much larger area than the anterior, its greatest vertical depth is ·9 of an inch. Its upper boundary, with that of the anterior coronal surface, forms an acutely pointed crest. The surface deeply concave and rough as though for the attachment of muscles. The posterior median ridge prominent with three or four wavy, imbricating folds, extending in an almost straight line across the spine; it is separated from the root by a deep groove. The root, separated from the anterior ridge by a sloping bony surface equal in breadth to that of the crown, is divided into fourteen to sixteen radicles or rootlets, circular, flattened, lobe-like; the flat sides lying parallel, separated by half their own diameter. The radicles are ·4 of an inch in length and the same width from back to front, they occupy a more forward position with respect to the crown of the tooth than any other species from the Armagh district.

In another example the anterior coronal surface from the median ridge backwards is much depressed, and forms a concave instead of a convex surface, towards the

back the surface rises and a sharp cutting edge is produced along the crest of the tooth. The anterior median keel in this specimen is devoid of a ganoine fold and is simply produced from the surface at a sharp angle.

The difference in the form of the crown of these specimens may be accounted for if one of the teeth has been derived from the lower and the other from the upper jaw, the convex surface of the one would fit almost perfectly to the concave surface of the other.

This species bears some resemblance to *Polyrhizodus littoni*, N. and W. (" Geological Survey of Illinois," Vol. II., p. 357 ; pl. iv., fig. 10). The American species is, however, less than half the size of *P. elongatus,* the anterior band or ridge is bow-shaped, with four closely approximated enamel folds, and there are only seven or eight radicles, which have not the same characters as those of the Armagh species.

Locality : Rare in the Carboniferous Limestone of Armagh.

Ex coll. Earl of Enniskillen.

Polyrhizodus sinuosus, Davis.

(Pl. LX., figs. 11, 12, 13.)

Teeth, considerable difference in size; largest examples 1·7 inch across the coronal surface, and 1·1 inch from crown to extremity of fangs; smallest size is ·4 across and ·34 in height; between the two a variety of intermediate sizes may be traced. Crown, flattened or slightly convex, compressed to a sharp edge along the crest; margins of the coronal surface unsymmetrical; crest for the most part straight, bent at each extremity—on the right at a sharp angle, and on the left at a more obtuse one—to form the lateral outlines; the anterior median ridge forms a sigmoidal curve, one-half the crown being double the diameter of the other. The greatest breadth is ·5 of an inch near the centre of the tooth; to the right this is reduced by the tenth of an inch, to ·25 of an inch, and becomes still more restricted towards its lateral extremity; in the opposite direction the crown maintains its greater breadth, ending laterally in an obtusely rounded margin. The ridge formed by the anterior margin is minutely corrugated transversely to its axis; the corrugations extend a short distance over the surface of the crown. The posterior coronal surface is not exhibited. A section of one of the teeth shows it to have been deep and extended far towards the base of the root. The inter-basal space recedes considerably from the anterior margin of the crown, forming a deep hollow preceding the base of the rootlets. Its surface is smooth, or very slightly punctured, the lower part corrugated contiguously with the insertion of the roots. The root is deeply fissured, forming four large, prominent globose radicles of unequal size. They are 1·35 inch across, being one-fifth less than the breadth of the crown.

In the smaller specimens the radicles are longer and more attenuated in proportion to the size of the tooth. The general form of the tooth, the peculiar sigmoidal

curve along the anterior median ridge, and straight crest of the coronal region appear, however, to be sufficiently indicative that they all belong to the same species, and that the difference in size represents only periods of growth.

A difference in form may be noted in this species which could not be easily observed in a symmetrical one. The peculiar curve in the median ridge in some of the teeth proceeds in the contrary direction to the one described above, and in place of the more attenuated extremity of the coronal surface being towards the right of the tooth, it is towards the left side. This difference leads to the inference that the teeth were in pairs in the mouth.

Locality: Mountain Limestone of Armagh.
Ex coll. Earl of Enniskillen.

Polyrhizodus attenuatus, Davis.

(Pl. LX., fig. 14.)

Teeth, extremely elongated in proportion to their height; length 1·8 of an inch; height ·5 of an inch. Crown elliptical, narrow, slightly convex, compressed to a thin, acutely-pointed, slightly-serrated edge along the nearly-straight crest; laterally the coronal surface is depressed towards the acutely-pointed lateral angles. The anterior margin forms a prominent ridge at a right angle to the basal area, almost straight in the median region, slightly rounded towards the base at each end; a single enamelled fold extends along its entire length; posterior face of the crown considerably deeper than anterior, slightly concave in each direction; slight striations extend from the minutely denticulated crest down the surface; lateral extremities obtusely rounded, with a slightly-raised border; basal border broad, with seven or eight delicately imbricating folds, moderately elevated above the coronal surface—more so above the basal area, from which it is separated by a groove. The anterior basal area occupies a space about equal to that of the crown. It is concave, and gently rounded towards the roots; upper surface distinctly pustulate, the spots placed indiscriminately, without arrangement; near the base of the rootlets, a peculiar series of duct-like striations terminating in a prominent pustule attached to each at its upper termination. Downwards the striæ descend to, and are absorbed in the general mass of the roots. The root divided into a variable number of radicles. The largest number is, perhaps, on the specimen figured, there being twenty-two. The radicles circular in section are irregular in size, and vary on the same specimen from ·2 to ·1 of an inch in length, the shorter ones generally being thin and small. The coronal surfaces are enveloped in a coating of ganoine, preserved on their lateral expansions, but generally worn off in the centre by the attrition of the grinding and cutting surfaces of the teeth. Where the surface beneath the enamel is exposed by its removal it is seen, when magnified, to be full of nutrient ducts, which ramify along the surface, with many devious sinuosities.

It was remarked, when describing *P. elongatus*, that one portion of the teeth have an anterior coronal surface which is convex, whilst another is concave along the same area. Some of the teeth belonging to the genus now being described exhibit the same peculiarity. Their general resemblance in other respects almost precludes the possibility of their being different species. They have about the same number of radicles to the roots; the posterior aspect of the tooth is the same in both, and the peculiar development of the duct-like marking on the anterior basal region is exactly the same in each. The anterior portion of the crown, however, offers several peculiarities differing in the two. The anterior coronal surface is concave, and more compressed along the crest, producing a very sharp cutting edge, slightly crenulated. The anterior median ridge is more prominent, and constitutes an acute angle with the upper basal area; and it is devoid of the band of enamel which stretches across the teeth already described. It appears probable that these were teeth from the upper jaw; whilst those with a convex crown have been derived from a lower jaw. As to whether there were several of the teeth forming concentric rows, as in the sharks, or whether they were arranged otherwise, there is no evidence, except the general character of the teeth, to show.

This species possesses characters which separate it from all others hitherto described. Its long, pectinated appearance and the number of its radicles, easily distinguish it. The one nearest resembling it is *P. piasœnsis*, St. J. & W. ("Geol. Surv. Illinois," Vol. VI., p. 386, pl. 13, fig. 12), it is little more than half the size, and possesses only nine or ten radicles.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Polyrhizodus constrictus, Davis.

(Pl. LX., fig. 15.)

Teeth, crown very small in comparison to the base or root. Greatest diameter of crown 1·1 inch; diameter of root along the same plane, 1·65 inch; depth of tooth from the surface of crown to bottom of roots, ·75 of an inch. The crown is narrow from back to front, not more than ·3 of an inch, smooth, and its central portion, much worn by trituration, rises at a slight angle from the anterior ridge to the crest; lateral extremities much raised; surface falling from each end towards the centre, and forming a deep concavity; anterior ridge continuous with the crown of the tooth without demarcation, but stands boldly forward above the narrow interbasal area; ornamented by four or five imbricating folds of the ganoine, by which it is covered; posterior surface partially imbedded in the matrix. It extends from the slightly rotund coronal crest to form a junction with the rootlets, and is not marked by any very distinct posterior ridge. The roots are large, tuberculous, broader than the crown of the teeth from back to front; the largest in centre ·45 of an inch in diameter. The rootlets towards each end of the tooth are smaller;

there are eight radicles preserved, two pairs being anchylosed. The spaces between the radicles are narrow in front, but expand to a greater width behind. The surface of the rootlets or radicles is indiscriminately pustulated or reticulated. Where fractured they show a close and fibrous texture.

This tooth is altogether dissimilar to any other species. It appears to be considerably worn by attrition along the surface of the crown; but it is not probable that its deep circular lateral concavity has been formed by the surface being worn away in this manner.

Formation and locality: Carboniferous Limestone of Armagh.

Ex coll. Earl of Enniskillen.

Genus.—Chomatodus, Agassiz.

"Teeth, transversely much elongated, compressed and depressed. Crown having the homologous parts of Petalodus, and the form and structure of Polyrhizodus—root short, sometimes obsolete, undivided."—(Worthen.)

In 1848 Prof. M'Coy added two new species to the genus Chomatodus, described in the Annals and Mag. of Nat. Hist., Vol. II., p. 115, as *C. obliquus* and *C. denticulatus.* Six years later his work on the British Palæozoic Fossils was published, in which (p. 617) after describing the general characters of Chomatodus, he writes, "This genus has, I think, no claims to be retained: the blunt-coned, thick species (as *C. cinctus,* &c.) might be advantageously classed with Helodus, most of the species of which, with the same form and punctured surface, have more or less perfectly developed imbricating folds at the base of the crown; and the thin unpunctured species with a cutting edge belong to Petalodus (Owen), in which the folds always exist. I use the genus here for some intermediate types provisionally, and for Agassiz's species."

Prof. M'Coy very accurately attributed little importance to the occurrence of a greater or smaller number of concentric folds around the base of the teeth, from which Agassiz instituted the genus Chomatodus. Such folds are present on a considerable number of genera, and in no way serve to distinguish them from each other. Of the three species of Chomatodus described and figured by Prof. Agassiz, the third *C. acuminatus* (Pois. foss., Vol. III., p. 108, Tab. 19, figs. 11, 12, and 13), is without doubt a species of Petalodus. It is an unique specimen discovered by Sir R. Murchison, in the limestone at Whorlton in Durham. Agassiz observes (op. cit., p. 159) that this species must be eliminated from the genus Chomatodus, because of its trenchant cutting edge, and placed with the Hybodonts, or more properly with the sharks (Squalides) properly so called. It will be included in the new genus Petalodus of Owen.

The second species *C. cinctus,* Agass., appears to be entirely composed of teeth which are indistinguishable from Helodus or Lophodus, and are now included in one or other of those genera.

The third species, *Chomatodus linearis*, Ag., possesses characters which separate some of the figured types clearly from both the genera Helodus and Petalodus, though there is evidently more than one genus represented. It is probable that the small somewhat circular and thin tooth (op. cit., Pl. 12, fig. 5) is a Petalodont, allied to the genus Antliodus, N. and W., whilst some of the figures have more than a passing resemblance to Ctenoptychius. The majority of the figures represent examples having an elongated, more or less straight, cutting edge ; surrounded or not by concentric folds or plicæ ; a somewhat expanded anterior and posterior coronal margin, and a short bi-concave root. These teeth pertain, in all essential respects, to a Petalodont type, very similar in form to the most elongated species of Polyrhizodus, except that the root or base is simple and undivided. Figs. 8, 9, 10, 12, and 13, *loc. cit.* seem to represent teeth possessing these characters, and may be taken as the types of the genus as now restricted.

Mr. Worthen, whilst describing a number of fossil fish remains found in Illinois, has adopted the same arrangement. The genus Chomatodus is retained by this accomplished ichthyologist, and the *C. linearis*, Agass., is taken as the type of the genus ; ten new species are then added from the sub-carboniferous limestone. The genus, as defined by Mr. Worthen, comprehends "teeth transversely much elongated, compressed and depressed, crown having the homologous parts of Petalodus and the form and structure of Polyrhizodus—root short, sometimes obsolete, undivided."

Chomatodus linearis, Agass.

(Pl. LXI., figs. 1, 1a.)

Psammodus	linearis—	L. Agassiz,	1833.	"Rech. sur les Poiss. Foss.," Vol. III., pl. xii., figs. 5–13.
"	"	P. de G. Egerton,	1837.	"Catalogue of Foss. Fishes."
Chomatodus	"	L. Agassiz,	1840.	"Rech. s. l. Poiss. Foss.," Vol. III., p. 108, pl. xii. figs. 5–13.
"	"	J. E. Portlock,	1843.	"Geol. of Londonderry, &c.," p. 446, pl. xiv., fig. 8.
"	"	C. G. Giebel,	1843.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 341.
"	"	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 293.
"	"	"	1849.	"Enumerator Palæont.," p. 647.
"	"	J. Morris,	1854.	"Cat. Brit. Foss.," p. 321.
"	"	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 266.
" (Helodus)	"	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 618.
"	"	Morris and Roberts,	1862.	"Quar. Jour. Geol. Soc.," Vol. XVIII., p. 100.
"	"	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 69.
"	"	Armstrong, Young, and Robertson,	1876.	"Catalogue West. Scot. Foss.," p. 60.
"	"	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 349.
"	"	L. G. de Koninck,	1878.	"Fauna du Calc. Carb. de la Belgique," p. 47, pl. vi., fig. 5.

Teeth, medium size, average about three times as long as broad, median ridge depressed, straight or slightly curved ; length 1·0 to 1·25 inch, breadth ·3 of an

inch, height of crown ·15 to ·2 inch. Crown: median ridge extends along central longitudinal axis, straight, uniform, without serrations or cones—anterior surface, slight convexity from apex to base; laterally straight or convex; posterior surface parallel with the anterior one, concave in both directions; anterior and posterior ridges somewhat expanded, margins occasionally serrated. Lateral borders oblique and angular. Coronal surface enamelled, apex deeply and coarsely punctate. A number of concentric imbricating folds or plicæ encircle the base of the crown, parallel with its margin. Base not well exposed, appears to be short, and deeply and doubly concave.

An example in the Enniskillen collection, from the Mountain Limestone of Richmond, in Yorkshire, differs in some respects from the Armagh type. The tooth is broader in the central portion in proportion to its length, laterally it becomes attenuated, and ends in a more or less acute point. The surface is punctate, and wide and irregularly sinuous folds extend along the anterior surface, most strongly marked near the apex, whilst near the base they are almost imperceptible. On the posterior surface the plicæ or folds are arranged concentrically; they are smaller and more numerous. Though this specimen differs in several respects from the type, and it is not improbable that it may belong to a separate species, yet it will perhaps be advisable to retain it with *Chomatodus linearis*, Ag., until more extended observation shall have demonstrated its real characteristics.

Formation and Locality: Mountain Limestone. Armagh, Bristol, Richmond in Yorkshire.
Ex coll. Earl of Enniskillen.

Chomatodus acutus, Davis.

(Pl. LXI., fig. 2, 2a.)

Chomatodus linearis, Ag., "Poiss. Foss.," p. 108, Tab. XII., fig. 5–13.

Tooth, not perfect, broken at one end, length preserved ·7 inch, depth anteriorly ·3 inch, posteriorly ·2 inch, width equal to the posterior height. Crown, transversely acuminate; apex, thin razor-shaped, with sharp cutting edge, straight; anterior and posterior surfaces concave with slight vertical corrugations, slightly expanded to form the ridges separating the crown from the base; base not exposed.

This species differs from *C. linearis*, Ag., in the acutely pointed knife-like apex of the crown, and in the constricted character of the anterior and posterior margins.

Formation and locality: Carboniferous Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Glossodus, M'Coy.

Glossodus.—F. M'Coy, 1848, Ann. and Mag. Nat. Hist., 2nd Ser., Vol. II., p. 127.

Teeth, tongue-shaped, oblong, quadrangular, much higher than wide; crown elevated, slightly recurved, narrowing from the base to a small, subtruncate apex; surface porous, puncta generally seeming confluent towards the

apex; punctured surface terminating below in a notch, or arched line, the convexity upwards; root long, as wide as crown, coarsely fibrous.—(M'Coy, Ann. Nat. Hist., Second Series, Vol. II., p. 127.)

A number of teeth of considerable diversity of form appear to be included in the above generic description. It is difficult, however, to distinguish amongst them specimens which exactly supply the characters ascribed by Prof. M'Coy to *Glossodus lingua-bovis* described in the volume of the Magazine of Natural History referred to, but not figured. The majority of the specimens belong to the species *G. marginatus,* M'Coy, also described in the Mag. of Nat. History, and afterwards figured in Brit. Palæoz. Foss., p. 629 Pl. 3 k., fig. 1. The latter, it is stated, may be easily distinguished from *G. lingua-bovis* by its more finely punctured, glossy surface, rounded tip and prominent lateral margins. These characters are possessed to a large extent by all the specimens, and those applied in the discrimination of *G. lingua-bovis,* viz., of possessing a dull surface, the antero-posterior diameter being only equal to half the width of the base, and the latter three times the width of the truncated apex, do not appear to be characteristic of any of the specimens. It is probable that all may belong to the same species, and as *G. marginatus* has been figured and redescribed by Prof. M'Coy, whilst *C. lingua-bovis* was not transferred forward to the Brit. Palæoz. Fossils, it will be preferable to retain the former specific name—though, as will be presently explained, the species will include a much wider variety than was contemplated by Prof. M'Coy.

Glossodus marginatus, M'Coy.

(Pl. LXI., figs. 3, 3a, 3b, 4, 5, 5a.)

Glossodus marginatus—	F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," Ser. 2, Vol. II., p. 128.
„ lingua-bovis,	„	1848.	„ „ „ Ser. 2, Vol. II., p, 127.
„ „	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 259.
„ marginatus,	„	1854.	„ „ Vol. II., p. 259.
„ „	J. Morris,	1854.	"Catal. Brit. Foss.," p. 327.
„ lingua-bovis,	„	1854.	„ „ p. 327.
„ marginatus—	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 629, pl. 3 K., fig. 1.
„ „	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
„ lingua-bovis,	„ „	1862.	„ „ „ Vol. XVIII., p. 100.
„ marginatus—	Young and Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 71.
„ „	Armstrong, Young, and Robertson,	1876.	"Catal. of W. Scot. Fossils," p. 61.
„ lingua-bovis—	J. J. Bigsby,	1878.	"Thesaurus Devonico-Carb.," p. 355.
„ marginatus,	„	1878.	„ „ „ p. 355.

Teeth, varying from 1 inch to ·2 inch in length; average example ·7 inch in length, ·25 inch across the base of the crown, and converging to an apex more or less shaped like a tongue, or in some instances much more acuminate—diameter from back to front equal or greater than the width of the base. The crown is elevated and

recurved backwards; anterior surface, occasionally much worn by attrition of an opposing tooth, is convex transversely, its lateral edges meeting those of the posterior surface, and forming more or less prominent lateral margins. The basal portion of the anterior surface is produced on each side of the median line to form a sub-angular prominence, from which the base proper retreats very rapidly, with a concave flexure, towards the posterior surface of the tooth. Posterior surface, more or less recurved near the apical extremity, concave, and laterally expanded; separated from the base by a sigmoidal curve. The whole coronal surface is enamelled and covered with punctures, the latter in some instances near the apex, being converted into anastomosing canals by the wearing of the surface. Base nearly as long as the crown, coarsely fibrous, extending vertically from the posterior coronal face, and with a deep concavity posteriorly.

A unique specimen occurs in the collection of the Earl of Enniskillen which exhibits a series of teeth *in situ*, showing, at any-rate in part, the arrangement of the teeth in the mouth (see Plate LXI., fig. 4). The specimen consists of three or four teeth, arranged one behind the other, in a very similar manner to those of Petalorhynchus or Janassa. The most anterior tooth is the smallest, and the series increases in size backwards, the tooth in use being the largest and most recent. By a peculiar arrangement the anterior sub-angular prominences, from the basal portion of the crown already mentioned, fit and are attached to corresponding depressions in the concave posterior surface of the preceding tooth. It is probable that five teeth occurred in each vertical series, and it is a natural inference that several of these vertical rows were extended side by side laterally.

There are examples of teeth which differ in details of form from the types described above. In some instances the apex is pointed, and the posterior basal part of the crown expanded so as to extend beneath the cone of the succeeding tooth (Plate LXI., fig. 5). These do not appear to be such differences as to render necessary the formation of a separate species, but may very well have been the teeth of either the opposite jaw or from a different part of the same jaw.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Genus.—Ctenopetalus, Agass., MSS.

Teeth of small or medium size; crown broad, compressed, gently rounded in outline; cutting edge divided into from twenty to thirty small denticles; base of crown possessing three or four imbricating folds of ganoine, descending lower on posterior than anterior surface; root narrower than crown, flattened, and about equal to it in height.

The genus Ctenopetalus along with that of Harpacodus originally constituted a part of the genus Ctenoptychius of Agassiz; they were named respectively *Ctenoptychius* (*Ctenopetalus*) *serratus*, Ag., and *C.* (*Harpacodus*) *dentatus*, Ag. They were both obtained from the Mountain Limestone; the other species of

Ctenoptychius, which are still included in the genus, are from the Coal Measures; so far as at present known the genus Ctenoptychius is not represented during the Carboniferous Limestone period. In 1859, Prof. Agassiz revised the group and made the above-named species form the types of new genera. These genera have not hitherto been described, but the types have remained in the collection at Florence Court. Professor Agassiz, in the "Poissons Fossiles," considered that the Ctenoptychians present a great resemblance to an Orodont squeezed flat. Their general form, however, is without doubt nearly related to the Petalodonts. The convex surface of the anterior face of the crown and the concave surface behind, form a very near resemblance to the petal-shaped tooth of Petalodus; they are distinguished by the deeply denticulated or pectinated cutting surface. "Whilst agreeing in the possession of a family likeness one with the other, they exhibit considerable generic distinctions. The genus Harpacodus differs from the other two in its thick, strong crown, and the almost straight contour formed by the enamelled tips of its denticles. The constricted, tumid, and prominent bony base is quite different from the flattened bases of Ctenopetalus and Ctenoptychius. The denticulation of the three genera is sufficiently distinct. Ctenoptychius, though possessing about an equal number of denticles with Harpacodus, is distinguished by their peculiar irregularly accuminate arrangement, whilst in Harpacodus they extend almost in a straight line across the tooth. The denticulation of Ctenopetalus is easily discriminated by the large number of denticles and their comparative smallness in proportion to the size of the tooth."

Ctenopetalus serratus, Agass. MSS.

(Pl. LXI., figs. 6, 6*a*, 7, 8.)

Ctenoptychius	serratus—L. Agassiz,		1833.	"Rech. s. l. Poiss. Foss," Vol. III., pp. 173, 383.
Petalodus	,,	R. Owen,	1840.	"Odontography," p. 62.
Ctenoptychius	,,	J. E. Portlock,	1843.	"Geol. Rept. on Londonderry," &c., p. 461.
,,	,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
,,	,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 356.
,,	,,	,,	1849.	"Enumerator Palæont.," p. 646.
,,	,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 324.
,,	,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 264.
,,	,,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 626, pl. 3I, figs. 21, 22, 23.
,,	pectinatus—E. W. Binney,		1855.	"Trans. Manchester Geol. Soc.," Vol. I., pl. v., figs. 20, 21.
Ctenopetalus	serratus—L. Agassiz,		1859	"Enniskillen Coll. MSS."
,,	,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,,	,,	Enniskillen,	1869.	"Cat. Type Specimens," p. 4.
Ctenoptychius	,,	Young & Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., Supt., p. 71.
Ctenopetalus	,,	Armstrong, Young, and Robertson,	1876.	"Catal. W. Scot. Foss." p. 61.
,,	,,	J. J. Bigsby,	1878.	"Thes. Devon.-Carb.," p. 353.
Ctenoptychius	,,	,,	,,	,, ,, p. 353.
Ctenopetalus	,,	J. W. Davis,	1881.	"Ann. and Mag. Nat. Hist.," p. 626.

Teeth; "Wide, much compressed, upper cutting edge having a gentle but variable convexity; usually divided into about thirty rounded notches, or obtuse pointed denticles, slightly larger in the middle than at the ends, and from between each pair of which a more or less distinct sulcus extends towards the base of the crown, rarely reaching more than halfway, and forming a fringe-like plication, and sometimes nearly obsolete; apices of the denticles minutely crenulated under the lens; front surface of crown flat, highly polished, sloping outwards, and terminating in an obtuse angle in the middle, and directed downwards and outwards; the very prominent base of the crown being surrounded by three or four flat imbricating bands of ganoine; root abruptly flattened, also narrower than the crown, and about equalling it in depth."—*M'Coy.* The posterior surface of the crown is deeply concave, smooth in the central part, plications at base of crown prominent, extending with considerable convexity towards the base and much lower than on the anterior surface. Coronal margin minutely serrated corresponding with the minor crenulations of the anterior surface, but the larger obtusely denticulated groups are not represented on the posterior face. Breadth of crown about ·8 of an inch; height of crown anteriorly ·3 inch; root one-third longer than the crown; posteriorly the crown is higher than the depth of the root.

Formation and locality: Mountain Limestone, Armagh.
Ex coll. The Earl of Enniskillen.

Ctenopetalus crenatus, Davis.

(Pl. LXI., figs. 9, 9*a*, 9*b*.)

Teeth, small, ·4 of an inch across the crown, and ·25 inch in height. Crown, anteriorly slightly convex between the lateral extremities; cutting edge slightly rounded, and divided into a number of minute denticles, smooth, obtusely-rounded, without minor division, which distinguishes them from *C. serratus.* Enamelled surface of the crown bounded below by several plicated folds of ganoine, the upper one enveloping the base of the crown. Lateral extremities of the front face acuminate, expanding towards the centre, which descends over the root with a prominently-advanced acute point. Posterior surface of crown concave, descending to nearly twice the depth of the anterior one, towards the root. Five or six broadly expanded plications occupy the base; root narrow, thin, anteriorly much contracted.

This beautiful little species possesses all the generic characters of Ctenopetalus, but is different in several respects from the type species *C. serratus* of Agassiz. It is less robust; the median portion of the anterior face of the crown forms an acute point, which in *C. serratus* is rounded and obtuse, and the apices of the denticles are smooth and undivided. This species bears a considerable resemblance to *C. medius,* from the Chester Limestone, Illinois ("Palæont. Illinois," Vol, VI., p. 400), but is distinguished by the pointed apex of the crown in the latter, by each denticle having

a short, sharp, crested carina, and by its possession of a single fold of enamel only along the base of the crown.

Formation and locality : Carboniferous Limestone, Wensleydale.
Ex coll. Wm. Horne, Esq., Leyburne.

Genus.—Harpacodus, Agass. MSS.

Ref.: "Annals and Magazine of Nat. Hist.," Dec. 1881, p. 424.

Teeth small ; crown slightly convex, strong ; cutting edge very slightly circular, divided into 5-8 deeply-cut, broad and strong denticulations; base of crown prominent, with a single broad fold of ganoine, deeper posteriorly than in front ; root at its junction with the crown much constricted ; lower it is expanded, large and tumid.

Harpacodus dentatus, Agass. MSS.

(Pl. LXI., fig. 10.)

Ctenoptychius dentatus—	L. Agassiz,	1833.	"Rech. s. l. Poiss. Foss.," Vol. III., pp. 173 and 383.
,, macrodus,	,,	1833.	"Rech. s. l. Poiss. Foss.," Vol. III., pp. 173 and 383.
Petalodus dentatus—	R. Owen,	1840.	"Odontography," p. 62.
Ctenoptychius macrodus—	J. E. Portlock,	1843.	"Geol. Rept. on Londonderry," p. 467, pl. xiv., fig. 7.
Petalodus dentatus,	,,	1843.	"Geol. Rept. on Londonderry," p. 467.
Ctenoptychius ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
,, macrodus	,,	,,	,, ,, ,, ,, ,,
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 356.
,, dentatus	,,	,,	,, ,, ,,
,, ,,	,,	1849.	"Enumerator Palæont.," p. 646.
,, macrodus	,,	,,	,, ,, ,,
,, ,,	J. Morris,	1854.	"Catal. Brit. Foss.," p. 324.
,, dentatus	,,	,,	,, ,, ,,
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 264.
,, macrodus	,,	,,	,, ,, ,, ,,
Harpacodus dentatus—	L. Agassiz,	1859.	"Enniskillen Coll. MSS."
,, ,,	Morris and Roberts,	1862.	"Quar. Journ. Geol. Soc.," Vol. XVIII., p. 100.
,, ,,	Enniskillen,	1869.	"Catal. Type Spec.," p. 5.
Ctenoptychius ,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 71.
,, (Harpacodus) ,,	Armstrong, Young, and Robertson,	1876.	"Cat. W. Scot. Foss.," p. 61.
,, ,, ,,	J. J. Bigsby,	1878.	"Thes. Devon.-Carb.," p. 353.
Harpacodus ,,	J. W. Davis,	1881.	"Ann. and Mag. Nat. Hist.," p. 426.

Teeth small, strong, ·4 inch in lateral diameter, ·4 inch in height ; height divided equally between the base and the crown. Crown oval in outline, laterally

convex, lower part thick and strong; crest slightly arched or straight, divided into about seven denticulations, large, broad at the base, laterally thin, and obtusely pointed; lateral denticles slightly smaller than those of the centre. The denticles divide the crown to one-half its depth, and between each the line of division is continued, forming a sulcus extending almost to the base of the crown. The latter is prominent, and forms a single broad fold or ridge extending across the anterior coronal surface, and on each side bending downwards, and thence enveloping the posterior surface of the crown. Posterior surface is concave laterally, and extends one-third lower from the apex than the anterior surface. Surface of crown is thickly enveloped with ganoine of a particularly hard and dense character, especially near the apex or crest. Base proportionately thick and strong, narrower than crown; anterior surface contiguous to crown much depressed for about one-third its vertical extent; below this the base is tumid, prominent, rounded and thick, fibrous, and close in structure.

Formation and locality: Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Harpacodus clavatus, Davis.

(Pl. LXI., fig. 20.)

Teeth, small and delicate, ·1 inch in height, and ·25 inch. broad. Crown, circular, base and apex, sub-parallel. Cutting edge divided into eight minute rounded, clavate, obtusely pointed denticles, coated with glistening enamel, diminishing with an extremely slight gradation in size towards each lateral extremity. The denticles occupy more than one-half the surface of the crown. Base of crown is imperfect, but was somewhat prominent, and apparently a fold of the ganoine separated it from the root. Posterior surface not visible. Root very short, conforming to the generally circular form of the crown—thick from back to front, and somewhat produced downwards at each end.

This species differs from *Harpacodus dentatus*, Ag., in its broad circular form and short low crown. The denticles are greater in number, well-defined, with a clavate, rounded extremity, those of *H. dentatus* being broader at the base, thin, with a laterally obtuse point. The base of this species is also quite distinct from that of *H. dentatus*, for whilst the latter is boldly prominent with a well-rounded tumid root, *H. clavatus* has a very short root, thick and widely expanded, and whilst it possesses the appearance of being perfect, it differs so much from the type specimen in this respect that it may be possible that a part of the root has been broken away.

Formation and locality: Mountain Limestone, Armagh. Unique specimen.
Ex coll. Earl of Enniskillen.

Genus.—Petalorhynchus, Agass., MSS.

Teeth, medium size, arranged in five or six horizontal rows of at least three teeth each, probably five or seven. Central primary teeth beak-shaped, lateral ones less pointed. Apex of crown constitutes a sharp cutting surface. Crown, anteriorly convex, with a median ridge extending from the point downwards to the base; posteriorly it is concave and spatulate; a series of four or five sigmoidal imbricating plicæ extend along both surfaces of the tooth, dividing the crown from the base; posterior coronal surface larger than anterior. Base, tapering, osseous, very long and undivided.

("Teeth, small; crown compressed, thin, concavo-convex petal-shaped, relatively higher and narrower than in Petalodus; imbricating folds on posterior face forming a short, transverse band, *not extending to the lateral angles of the crown*; root long, undivided."—*Newberry and Worthen.*)

Petalorhynchus psittacinus, Agass., MSS.

(Pl. LXI., figs. 12, 13, 14, 15, 16, 16*a*, 16*b*.)

Chomatodus accuminatus?—	L. Agassiz,	1833.	"Rech. sur les Poiss. Foss.," Vol. III., p. 108. (partim).
Petalodus psittacinus—	L. Agassiz,	1840.	"Rech. sur les Poiss. Foss.," Vol. III., pp.174. and 384.
,, sagittatus,	,,	1840.	"Rech. sur les Poiss. Foss.," Vol. III., pp.174 and 384.
,, ,,	J. E. Portlock,	1843.	"Geol. Report on Londonderry, " p. 461.
,, psittacinus,	,,	1843.	,, ,, ,, p. 461.
,, ,,	C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 345.
,, sagittatus,	,,	1848.	,, ,, ,, Vol. I., pt. 3, p. 345.
,, ,,	H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 949.
,, psittacinus,	,,	1848.	,, ,, p. 949.
,, ,,	,,	1849.	"Enumerator Palæont.," p. 646.
,, sagittatus,	,,	1849.	,, ,, p. 646.
,, ,,	J. Morris,	1854.	"Cat. Brit. Foss.," p. 337.
,, psittacinus,	,,	1854.	,, ,, ,, p. 337.
,, ,,	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 272.
,, sagittatus,	,,	1854.	,, ,, ,, Vol. II., p. 272.
,, psittacinus,	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 636, pl. 3 i, fig. 4.
,, sagittatus,	,,	1855.	,, ,, ,, p. 636, pl. 3 i, figs. 2, 3.
Petalorhynchus psittacinus—	L. Agassiz,	1859.	"Enniskillen Coll., MSS."
,, ,,	Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
Petalodus sagittatus—	,,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.

Petalorhynchus	psittacinus—	Enniskillen,	1869.	"Catalogue Type, Spec.," p. 7.
Petalodus	,,	Young & Armstrong,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 74.
,,	sagittatus—	,,	1871.	"Trans. Geol. Soc., Glasgow," Vol. III., Supt., p. 75.
Petalorhynchus	psittacinus	Armstrong, Young, and Robertson,	1876.	"Catal. of West Scot. Foss.," p. 62.
,,	,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 361.
,,	,,	J. W. Davis,	1881.	"Rep. Brit. Assoc.," p. 646.

Teeth, medium size, consisting of, at least, three vertical and five transverse rows of teeth in each jaw; form much varied in different parts of the mouth according to situation. Crown generally longer and narrower in central row, and broader and shorter laterally; spatulate. Base very long in primary horizontal row, diminishing in the teeth occupying second and succeeding rows; length of average specimen, 1·0 to 1·5 inch; breadth of crown, ·6 to ·8 of an inch; length of crown, anteriorly, one-third that of base; posteriorly, slightly longer than its breadth. Crown acutely angular, with a sharp cutting edge, pointed in the middle, resembling the beak of a parrot; anterior surface laterally convex; median portion, from the point downwards, forming a prominent ridge, laterally expanded and depressed with thin circular margins. Anterior ridge separating crown from base, extends sigmoidally across the surface; ornamented with four or five folds of ganoine extending slightly upwards on each side from the central ridge of the tooth, and recurved towards the lateral margins of the crown, forming with them an acutely-pointed decurrent angle. Posterior surface deeply concave, spoon-shaped, nearly twice the length of the anterior surface; posterior ridge covered with an equal number of enamelled folds, continuous with those on the anterior surface; from the lateral margins they curve downwards towards the base, then recurving sigmoidally meet and unite on the median line. Root, like the crown, varies in form in accordance with the position occupied in the arrangement of the teeth. In a typical example from the primary row of teeth, the root is twice as long as the anterior face of the crown, and from the point of its connexion with the crown gradually diminishes in diameter to the bottom. On the anterior surface, the central coronal ridge is continued downwards to the base, at first expanding in width for about one-third the length of the root, afterwards gradually contracting. On either side the ridge is a deep sulcus which extends to the lateral margins. Posteriorly, the root is depressed medially, with a slight ridge on each side, from which the surface slopes to the lateral margins, termination of base obtusely angular. The coronal surface is smooth, or very slightly punctate, enamelled, and highly polished: cutting edge of crown in most cases smooth, occasionally very slightly imbricated. The crown is frequently worn along the edge, on one side only, in such a manner that the effect could only be produced by the grinding action of an opposing tooth, which served at the same time to

keep the cutting edge of the tooth sharp. Descending from the apex of the convex anterior coronal surface there is in some cases a closely approximating series of open ducts or canaliculæ, they are about an eighth of an inch in length and extend with a slightly sinuous line and not unfrequently bifurcate.

The general resemblance of some of the lower teeth of Petalorhynchus to those named by Professor Agassiz, *Chomatodus truncatus* (Pois. Foss. vol. iii. p. 174), and afterwards described by Professor M'Coy, as a Petalodont form of Chomatodus (Brit. Palæoz. Foss. p. 618, pl. 31, fig. 1), strongly suggests the probability that the two genera may have appertained to the same fish. They are described by Professor M'Coy as being "longitudinally oblong, sides of crown and root sub-parallel, except at the upper and lower ends, when they rather abruptly converge to form the subtruncate, slightly rounded cutting edge at top, and the rather more pointed lower end of the root; crown flattened, bent at an angle of 120° with the long root which is nearly straight in profile; surface of the crown finely punctured as in Psammodus; root, hard and polished, with two or three obscure longitudinal furrows, almost entirely surrounded by a raised marginal extension of the thick, prominent, simple, coronal ridge; the posterior side is concave. Length six and a half lines, width six lines, length of crown two lines."

Count Münster has described a series of teeth of Janassa (Beiträge zur Petrefactenkunde, Heft V. p. 38, tab. 15, fig. 10–14), which appear in all more important particulars to have possessed great similarity in arrangement to those of Petalorhynchus. In Janassa the terminal teeth are similar in form to certain Petalodonts, and it may perhaps be assumed that the teeth hitherto known as *Chomatodus truncatus*, were the terminal teeth of Petalorhynchus. They differ considerably in form, but the teeth which are undoubtedly Petalorhynchus, bridge over the difference between the sharp, long pointed form of the central teeth and those, even and flat crowned, which occupied each posterior extremity of the jaw. Awaiting evidence to the contrary they are here included with Petalorhynchus.

Three species of Petalorhynchus are described from the upper beds of the St. Louis Limestone, of Illinois (Palæont. of Illinois, vol. VI. p. 405–409, pl. XII., figs. 1–8). *P. pseudosagittatus* St. J. and W. is described as an example of the intimate specific relations existing between the European and American Carboniferous fishes. It very nearly approaches *P. sagittatus* Agass., from the Limestone of Armagh, but "is distinguished by its shorter base, less rapidly converging outline of the crest, and the more numerous imbrications of the coronal belt." Considering the extreme variety in the form, size, and characteristics which exist amongst the numerous specimens from Armagh, it is slightly problematical if the above differences are sufficient to constitute a separate species. The same remarks may apply to *P. distortus*, St. J. and W., it is possibly a lateral tooth of *P. pseudosagittatus*, the twist in the crown being due to its position in the mouth. The third species *P. spatulatus* is principally characterized and distinguished by its broadly expanded base,

and is described as holding a similar relationship to *P. pseudosagittatus* that *P. psittacinnus* does to *P. sagittatus* in the Carboniferous Limestone of Armagh, which may be correct.

Formation and locality: Mountain Limestone, Armagh.

Ex coll. Earl of Enniskillen.

Genus.—Pristodus, Agass. (MSS.)

Diodontopsodus.—Davis, 1881. "Rept. Brit. Assoc.," 1881, p. 646.

Teeth, medium size, beak-shaped, with a semicircular trenchant cutting edge, upper jaw deeply serrated; crown consists of a vertical surface enveloping the jaws externally, deep anteriorly and diminishing in size posteriorly on each side; at right angles to the vertical portion, an expansion of the bony surface forms a palate, extending backwards to a line with its two latero-posterior extensions, junction of surfaces produced to form a more or less acute cutting edge. Surface enamelled, smooth or slightly punctate.

Pristodus falcatus, Agass. (MSS.)

(Pl. LXI., figs. 17, 18, 19, 20, 21, 22.)

Pristodus falcatus—	L. Agassiz,	1859.	"Enniskillen Coll. MSS."
,, ,,	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, ,,	Enniskillen,	1869.	"Type Specimens of Foss. Fishes," p. 7.
,, ,,	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 363.

Teeth. Two forms; in those of upper jaw the cutting edge is largely extended and divided into a series of ten to fourteen deeply cut serrations, largest in the centre and diminishing in size backwards. The denticles are triangular in outline, broad at the base, converging to an acutely pointed apex. In each example the centre of the tooth, which envelopes the whole external surface of the jaw, is the line of division between the two largest serrations, one extending on each side; in no instance does one of the denticles occupy the median line. The vertical length of the tooth is ·5 inch from the upper palatal portion to the extremity of the serrated cutting edge. It is semicircular in outline, diminishing in height posteriorly, and the cutting edge extends obliquely forward from above downwards. The lower jaw was enveloped in a somewhat similar bony investment, but whilst in the upper jaw the serrated cutting edge extended from the palatal surface and formed a long cutting edge, in the lower jaw the cutting edge is not serrated and extends only a short distance beyond the horizontal palate. It is produced and pointed in the centre, in the form of a beak, from which the surface of the crown descends on each side, forming only a slight ridge towards the posterior portions of the tooth. The vertical portion of the lower tooth is slightly convex, its lower margin extending downwards in front of the jaw, forming an acute point, and from

this curving gradually upwards on each side towards the backwardly extended palate. The palatal surface is concave, its anterior margin is formed by a semicircular cutting-edge, the posterior margin extends with a slightly inward flexure between the two latero-posterior extremities. The teeth consist of a thin bony shell, the internal surface conforming generally to the external one, and enveloping the cartilaginous jaws. There is no distinct base or root. The surface is thinly but uniformly coated with enamel, smooth or slightly punctate.

Messrs. St. John and Worthen, in the "Palæontology of Illinois" (Vol. VI., p. 402, pl. Xa., fig. 6), refer a minute tooth, ·09 inch in lateral diameter, to the genus Pristodus. Judging from the description and figure, the tooth has the serrated cutting edge, similar to that of Pristodus, as represented in the teeth from the Yoredale Limestones of Yorkshire, and it bears a further likeness in having no appreciable basal region. Leaving its small size out of consideration, it differs from Pristodus in several important particulars; it does not extend in a semicircular form backwards at the latero-posterior extremities of the tooth and has much more the appearance of having constituted one of a series of teeth in the shark-like types, or, as is suggested by the authors, to one of those curious little fossils known under the general term Conodonts, than to the singular arrangement in Pristodus. In the latter there are always two central prominences or cusps of the coronal surface, one on each side the median line, which are equal in size, whilst in the specimen from the Kinderhook fish-bed there is only one central prominence. The Yorkshire specimens are devoid of any imbrications or folds extending along the base of the crown; they are present in the *P. acuminatus,* St. J. & W. It is improbable that this tooth can be retained in the genus Pristodus.

The teeth are probably unique in their characteristics amongst the fishes of the Palæozoic rocks. A single tooth appears to have enveloped the whole of the jaw, upper or lower as the case may be. Those of the upper jaw differed considerably from the lower. A strongly-serrated, trenchant, cutting-edge descended from and encircled the palatal portion of the crown. The serrations, having the character of a number of teeth or denticles anchylosed together, decrease in size backwards, the largest on each side the median line of the tooth occupying about one-third its vertical length; broadly implanted they converge triangularly to an acute point.

The tooth of the lower jaw is devoid of serrations and presents a surface, produced to form a single apical point in the centre, but otherwise plain and smooth. It is smaller than the upper tooth, and when the mouth of the fish was closed, the serrated portion of the latter enveloped the lower jaw extending far over its anterior surface, this is clearly shown by a specimen in the Collection of Mr. William Horne of Leyburn. The upper palatal portion of the jaw in this specimen is broken off, leaving the circular vertical part deeply serrated as usual and about a quarter of an inch in depth. The interior of the tooth is filled up with a matrix of limestone, and projecting from this is the pointed apex of the

tooth of the lower jaw. It is situated just within the central part of the tooth of the upper jaw. The palatal surface of the tooth of the lower jaw is characterized by considerable lateral convexity; and is produced in front to form the beak-like prominence. Inside each lateral margin, there is a deep sulcus, the palatal and vertical portions uniting to form an acuminate and well-developed cutting-edge. The palatal surface of the upper tooth is as nearly as possible the counterpart of the lower, so that the two surfaces correspond and fit to each other when closed.

The interior of the tooth is hollow, the enamelled osseous part forming a thin shell-like covering to the cartilaginous jaws. There is no portion which can be distinguished as the root or base of the tooth, the attachment to the jaw apparently being entirely on the inside.

In searching for the zoological relationship of Pristodus, a striking and most peculiar resemblance is at once observed between it and some of the Gymnodont group of the Plectognath group of fishes at present existing. These fishes are characterized by the possession of jaws which in some instances consist of a single undivided dental plate to each jaw. In others, the dental arrangement consists of two upper and two lower dental plates, divided by a mesial suture. The first group is the one to which the Mountain Limestone fossils bear the greatest resemblance. The existing group comprises about seventeen species, which are frequently found in the Tropical Atlantic and Pacific seas. A common example is *Diodon maculatus*, which may be taken for comparison with the fossil forms. It is unnecessary for our present purpose to consider more than the dental arrangement. In an example six inches in length from the snout to the base of the tail, the oral aperture is eight-tenths of an inch in width, and both the upper and lower jaw is provided with a single semicircular dental plate, extending backwards into the mouth, in the form of a palate. The front edge is slightly produced and somewhat beak-like, the teeth extending upwards and downwards respectively, encircling the outer aspect of the jaw and forming in section two sides of a triangle, the third side being occupied by the soft internal muscular or cartilaginous attachment for the tooth. This dental arrangement is admirably adapted to break up masses of coral, or the hard shells of molluscs and crustaceans on which the fishes feed. The upper dental plate extends slightly beyond, and overlaps the lower one; it is slightly more produced or pointed in the centre. Posteriorly, the upper and lower jaws are strongly united by ligaments and muscles, the upper extending over and embracing the lower.

The genus Diodon occurs in a fossil state in the tertiary limestone of Monte Bolca and Licata, and from Monte Postale, Enneodon, a distinct genus has been found and described.

In many respects the fossil teeth from the Mountain Limestone of Yorkshire, bear considerable resemblance to those of Diodon. In the general form of the palatal interior, combined with the semicircular external, trenchant edge of the

tooth, the two are almost identical. The fossil examples do not appear to have had an osseous prolongation posteriorly for the muscular attachment of the upper and lower jaw, but this may be due either to the imperfection of the specimens, which are rarely perfect, or perhaps, more probably to difference in the organization of the fishes. Diodon is ranked amongst the Teleostean fishes, with an imperfectly ossified skeleton; fins mostly soft, skin naked, except where it has developed osseous spines, the latter capable of extension for the fish's protection, by the inflation of its body. The fossil genus Pristodus is represented only by its teeth, no other portion of its remains have been identified, and it may be inferred that it was a fish possessing a cartilaginous skeleton, and probably devoid of dermal spines or appendages. The skeleton being unossified, it naturally results that only the teeth are preserved in a fossil state.

A comparison of the recent and fossil teeth, however, leads to a natural inference of relationship in some degree, however remote. Evidence is entirely wanting as to the anatomical structure of Pristodus, and I do not wish to lead to the inference that it was more nearly related than is warranted by the peculiar similarity of the teeth. There is a sufficiently special and peculiar adaptation of the jaws and teeth, of the two groups, to prove that it is not entirely an accidental one, we know that the teeth of the recent Diodon are admirably suited to the food on which it exists, for the purpose of breaking the hard coverings of corals or molluscs, and there is every reason to believe that those of the fossil forms were equally adapted to preying on the corals, crustacea and brachiopods existing in so great abundance in the carboniferous seas.

Formation and locality: Yoredale Limestone, Richmond.
Ex coll. Earl of Enniskillen.

Genus.—Cheirodus, M'Coy.

Cheirodus.—F. M'Coy, 1848. "Ann. and Mag. Nat. Hist.," 2nd ser., Vol. II., p. 131.

"General form of Ceratodus, that is, more or less fan-shaped, thick, flattened, with the anterior broad margin deeply divided into lobes; but the inner nearly-straight margin has a small recurved, thumb-like lobe projecting nearly at right angles from the middle of its length, preventing the mesial junction of the tritors of each side of the jaw: the inner marginal lobe is the longest; surface minutely punctured."—(*M'Coy.*)

Cheirodus pes-ranæ, M'Coy.

(Pl. LXIII., figs. 5, 5a.)

Cheirodus pes-ranæ—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist." 2nd ser., Vol. II., p. 131.
" "	J, Morris,	1854.	"Catal. Brit. Foss," p. 321.
" "	F. J. Pictet,	1854.	"Traité de Paléont," Vol. II., p. 269.
" "	F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 616, pl. 3 G, fig. 9.
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 99.
" "	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 349.

Teeth, length ·65 of an inch, narrow; anterior lobes narrow, prominent, rounded, arched, separated by deep concave furrows; the inner lobe about a line longer than the next outer one: at the base of the former, or about half the length of the whole tooth, there projects horizontally inwards from the inner margin a short, wide, slightly recurved, flattened lobe, about ·1 inch long; posterior part of the tooth flattened: surface under a lens finely punctured.

This species is founded on a single specimen in the Woodwardian Museum. In general appearance it resembles the teeth of Ceratodus of the Devonian rocks.

Formation and locality: Shales in Mountain Limestone, Derbyshire.

Ex coll. Woodwardian Museum, Cambridge.

Genus.—Colonodus, M'Coy.

Colonodus.—F. M'Coy, 1848. "Ann. and Mag. Nat. Hist.," 2nd ser., Vol II., p. 5.

"Tooth, elongate-conic, very gradually tapering, section round near the base, becoming trigonal towards the apex: front even, sides impressed with short, alternating, transverse wrinkle-like furrows; enamel-like surface smooth, highly polished, longitudinally marked with few, distant, minute impressed striæ; it terminates obliquely at the base, the edge being slightly notched or wrinkled: base forming a short slightly dilated round disc, placed obliquely to the axis of the tooth, and extending further behind than in front, truncated below, and of a coarse osseous texture; medullary cavity about one-third the diameter of the tooth, cylindrical, from which, under the microscope, the flexuous, distant calcigerous tubes are seen to radiate directly to the surface, towards which they become gradually finer and closer."

Colonodus longidens, M'Coy.

(Pl. LXIII., fig. 6.)

Colonodus longidens—	F. M'Coy,	1848.	"Ann. and Mag. Nat. Hist.," 2nd ser., Vol. II., p. 5.
" "	J. Morris,	1854.	"Catal. Brit. Foss." p. 323.
	F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 149.
" "	Morris & Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 100.
" "	J. J. Bigsby,	1878.	"Thesaurus Devon.-Carb.," p. 351.

Prof. M'Coy remarks of this species, that it is an almost perfectly straight, cylindrical tooth, the apex being unfortunately wanting, but enough remains to show that towards the extremity the anterior face becomes flattened so as to give an obscurely trigonal section : there are two alternating rows on each side of about thirteen or fourteen short transverse furrows, forming between them obscure wrinkles : the whole surface to the naked eye seems smooth and highly polished, but under a low power, the fine, impressed, rather distant longitudinal sulci become visible. The whole tooth seems directed backwards at a considerable angle from its round bony base, and the inferior termination of the enamel-like portion is therefore very oblique to the axis of the tooth, being considerably lower in front than behind, the edge seeming of considerable thickness from a sharp constriction being immediately under it all round, beneath which again the osseous base thickens to form a little peltate mass. The length of the portion preserved is ·9 of an inch, width at base ·3 of an inch, diminishing towards the apex to ·15 of an inch.

This peculiar form, at present in the Museum of the Geological Society of London, which served as the basis of the above description in 1848, still remains unique. It differs very much from any other teeth discovered in the Mountain Limestone. Its relationship is considered by Prof. M'Coy, to be with Rhizodus or Dendrodus, and consequently that it is the tooth of a ganoid fish, but the likeness is somewhat remote, and awaiting further discoveries, it may be as well to withhold any opinion as to its zoological affinities or position.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Jones Collection, Museum of the Geological Society, London.

Genus.—Cœlacanthus, Agass.

(Pl. LXIII., figs. 7–12.)

Several detached plates of a species Cœlacanthus have been found in the limestone at Armagh. They consist of an operculum, jugular plates, mandible, and other bones of the head as well as some scales. They possess the characteristic surface ornamention of the genus and probably belong to the species *C. lepturus*, Agassiz.

Formation and locality : Mountain Limestone, Armagh.
Ex coll. Earl of Enniskillen.

Genus.—Oracanthus.

Oracanthus milleri, Agass.

(Plate LXII., figs. 1–13, Pl. LXIII., figs. 1–4, Pl. LXIV., figs. 1, 2, Pl. LXV., figs. 3, 4.)

Ichthyodorulithes curvicostatus, Buckland and De la Beche, MSS., Bristol Museum.

Oracanthus milleri—L. Agassiz,	1833.	"Rech. sur l. Poiss. Foss." Vol. III., p. 13, pl. iii, figs. 1, 2, 3 & 4.
,, pustulosus, ,,	1833.	,, ,, ,, ,, Vol. III., p. 15, pl. ii, figs. 3, 4.
,, minor, ,,	1833.	,, ,, ,, ,, Vol. III., p. 16, pl. iii, figs. 5, 6.
,, confluens, ,,	1833.	,, ,, ,, ,, Vol. III., p. 177, indet.
,, ,, J. E. Portlock,	1843.	"Rept. Geol. Londonderry," p. 461.
,, minor, ,,	1843.	,, ,, ,, p. 461.
,, milleri— C. G. Giebel,	1848.	"Fauna der Vorwelt," Vol. I., pt. 3, p. 303.
,, pustulosus, ,,	1848.	,, ,, ,, Vol. I., pt. 3, p. 303.
,, minor, ,,	1848.	,, ,, ,, Vol. I., pt. 3, p. 303.
,, confluens, ,,	1848.	,, ,, ,, Vol. 1., 3, pt. 303.
,, ,, H. G. Bronn,	1848.	"Nomencl. Palæont.," p. 847.
,, milleri, ,,	1848.	,, ,, p. 847.
,, minor, ,	1848.	,, ,, p. 847.
,, pustulosus, ,,	1848.	,, ,, p. 847.
Coccosteus ? carbonarius—F. M'Coy,	1848.	"Ann. & Mag. Nat. Hist.," 2nd ser., Vol. II., p. 9.
Asterolepis verrucosa, ,,	1848.	,, ,, ,, ,, 2nd ser., Vol. II., p. 9.
Platycanthus isoscéles, ,,	1848.	,, ,, ,, ,, 2nd ser., Vol. II., p. 120.
Oracanthus confluens, ,,	1849.	"Enumerator Palæont.," p. 649.
,, milleri, ,,	1849.	,, ,, p. 649.
,, minor, ,,	1849.	,, ,, p. 649.
,, pustulosus, ,,	1849.	,, ,, p. 649.
,, confluens—J. Morris,	1854.	"Catal. Brit. Foss.," p. 334.
,, milleri, ,,	1854.	,, ,, ,, p. 334.
,, minor, ,,	1854.	,, ,, ,, p. 335.
,, pustulosus, ,,	1854.	,, ,, ,, p. 335.
Coccosteus ? carbonarius, ,,	1854.	,, ,, ,, p. 322.
Asterolepis verrucosa, ,,	1854.	,, ,, ,, p. 318.
Platycanthus isosceles, ,,	1854.	,, ,, ,, p. 339.
Oracanthus milleri—F. J. Pictet,	1854.	"Traité de Paléont.," Vol. II., p. 284.
,, pustulosus, ,,	1854.	,, ,, Vol. II., p. 284.
,, minor, ,,	1854.	,, ,, Vol. II., p. 284.
,, confluens, ,,	1854.	,, ,, Vol. II., p. 284.
Coccosteus ? carbonarius, ,,	1854.	,, ,, Vol. II., p. 221.
Asterolepis verrucosa, ,,	1854.	,, ,, Vol. II., p. 150.
Platycanthus isosceles, ,,	1854.	,, ,, Vol. II., p. 292.
Oracanthus milleri—F. M'Coy,	1855.	"Brit. Palæoz. Foss.," p. 634.
,, confluens—Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
,, milleri, ,,	1862.	,, ,, ,, ,, Vol. XVIII., p. 101.
,, minor, ,,	1862.	,, ,, ,, ,, Vol. XVIII., p. 101.
,, pustulosus, ,,	1862.	,, ,, ,, ,, Vol. XVIII., p. 101.

Platycanthus isosceles—Morris and Roberts,	1862.	"Quart. Journ. Geol. Soc.," Vol. XVIII., p. 101.
Coccosteus carbonarius, "	1862.	" " " " Vol. XVIII., p. 100.
Oracanthus milleri—Young and Armstrong,	1871.	"Trans. Geol. Soc. Glasgow," Vol. III., Supt. p. 73.
" minor, "	1871.	" " " " Vol. III., Supt. p. 73.
" milleri—Armstrong, Young & Robertson,	1876.	"Catal. W. Scot. Foss.," p. 62.
" minor, "	1876.	" " " p. 62.
" confluens—J. J. Bigsby,	1878.	"Thesaurus Dev.-Carb.," p. 359.
" milleri, "	1878.	" " " p. 359.
" minor, "	1878.	" " " p. 359.
" pustulosus, "	1878.	" " " p. 359.
Asterolepis verrucosa, "	1878.	" " " p. 347.
Coccosteus carbonarius, "	1878.	" " " p. 349.
Platycanthus isosceles, "	1878.	" " " p. 363.
Oracanthus milleri—de Koninck,	1878.	"Fauna du Calc. Carb. de la Belgique.," p. 69, pl. v., fig. 10.

In the early part of the present century some specimens of a large Ichthyodorulite were found in the Black Rocks at Clifton, near Bristol, by Dr. Miller. They were deposited in the Bristol Museum, and were named by Buckland and De la Beche, *Ichthyodorulithes curvicostatus*, they were not, however, described by these authors. They were considered to be the spines of a fish of Elasmobranch type, the specimens were of large size, very wide at the basal end, and their exposed surfaces were ornamented by prominent pustulations. The base did not exhibit evidence of having been so deeply implanted in the integuments as is generally observed in other genera. Prof. Agassiz described and gave figures of the specimens in his "Recherches sur les Poissons Fossiles." The genus Oracanthus was instituted for their reception, and the specimens were arranged in three species, being *O. pustulosus*, *O. minor*, and the third in honour of its discoverer, *O. milleri.*

Oracanthus pustulosus is the largest in size, it is described as being very thin, much compressed, with a very spacious internal cavity, the external surface is covered with tubercles disposed irregularly over the spine and most numerous on the inferior margin. *O. milleri* is distinguished by the tubercles being arranged in oblique rows or running into each other so as to form irregularly oblique ridges. The third species, *O. minor*, is very small and it is pointed out by Prof. Agassiz, that it may have been the point of a larger specimen, but that on comparison with the apex of spines of either of the other species he has found that it is very considerably narrower in proportion to its length; its external appearance it is stated very much resembles the claw of a crab, but its internal structure certainly indicates its position to be in the genus Oracanthus.

In addition to the three species from the Bristol Limestone, a fourth was discovered in the Limestone of Armagh, which Prof. Agassiz, named *O. confluens*, but did not describe.

Prof. M'Coy, considered that *O. confluens* was the same species as *O. milleri*, and also that *O. minor* was simply the point of the spine *O. milleri.* It is further

remarked that "the extremely puzzling and protean character of the surface proportions, and frequent distortions of this ray are certainly due to its most extraordinary character, which has entirely escaped M. Agassiz, viz.:—the extreme thinness of the substance and the great size of the internal cavity. . . . It is owing to this thin hollow construction that some specimens are flattened laterally, showing oblique ridges, and some flattened from before backwards, showing the ridges meeting at a salient angle. This explanation also dispels all the difficulties under which M. Agassiz laboured, as to the direction of the ridges, and the position of the faces of the spine." This statement has been repeated by M. de Koninck in the "Fauna du Calc. Carbonifére de la Belgique," (1878.) A reference to Prof. Agassiz's descriptions of the species, however, shows quite clearly that he was well aware of the facts stated by Prof. M'Coy, whilst the deductions of the latter, as will be seen by further reference to Pl. LXIV., figs. 1 and 1a, are evidently fallacious.

Two or three fragments of osseous dermal plates are described by Prof. M'Coy ("Annals and Magazine of Natural History," 2nd Ser., Vol. II., p. 9), as representatives of the Devonian genera Coccosteus and Asterolepis. The latter consists of an irregular fragment an inch and a quarter long, and less than half an inch wide, but "it is impossible to suggest what part of the body it belonged to." Two small specimens are very doubtfully referred to Coccosteus. The several fragments are represented on Plate LXII., figs. 14, 15; they are from the Mountain Limestone of Armagh, and form part of the Jones Collection at the Geological Society of London.

Platycanthus isosceles, M'Coy, (Pl. LXII., fig. 9), is described by M'Coy (op. cit., p. 120), as a triangular ray, very wide, the length of the base nearly equalling the height of the spine, arched backwards, much compressed, sides flat, surface pustulated, and having two rows of sharp conical teeth on the posterior face. It very much resembles Oracanthus, but differs in its small size, arched form, and posterior rows of teeth, which also distinguishes it from Byssacanthus of the Old Red Sandstone. This species is also from the Limestone of Armagh.

Since the preceding descriptions were written an extensive series of specimens have been added to the comparatively small number known to Prof. Agassiz; and the imperfect specimens which served for illustration in the "Poissons Fossiles," can now be supplemented by others more completely illustrating the characters and peculiarities of the fishes to which they formerly pertained. Notwithstanding this increased mass of material there is so much diversity of form, and the structure of the objects hitherto regarded as dorsal spines is so widely aberrant from the normal plagiostomous types, such as Ctenacanthus, that, as will be explained hereafter, it is very doubtful whether they can be regarded as spines, and not rather as the dermal covering of some portion of the body of the fish. It may be advisable before attempting a detailed description of the specimens to briefly glance at their general characteristics and more salient points of difference and if possible divide them into two or more groups.

The Ichthyodorulites described by Prof. Agassiz, and included in the genus Oracanthus have the following characters in common. *Oracanthus pustulosus* and *O. milleri* are very broad in comparison to their length; the external bony part is extremely thin and the internal cavity excessively large; they are laterally compressed, acutely pointed, and the basal portion, unlike other genera of the Plagiostomata, is covered to the extremity with the same external ornamentation which is characteristic of the exposed surface, there being no evidence that any part of the base was implanted in the integuments of the fish. The difference between the two species consisting in the style of ornamentation, *O. pustulosus* being studded with tubercles arranged indiscriminately over the surface, whilst on *O. milleri,* the tubercles were extended in oblique rows across the surface or closely approximated, they formed oblique ridges. *Oracanthus confluens,* which Prof. Agassiz named in manuscript from specimens in the Enniskillen collection, was found at Armagh, the two previously mentioned being from the Bristol Limestone. *O. confluens* may be distinguished from *O. pustulosus* and *O. milleri* by the extreme width of its base. An example measuring 3·3 inches on its shorter side, between the point and the base, is 3·0 inches across the base, so that the width of the base is nearly equal to the length, whilst in *O. milleri* the length from point to base is more than double the basal diameter. The surface is covered with pustulations which in some specimens assume a definite arrangement, or form ridges by the coalescence of the tubercles, whilst in others there is no definite arrangement. Specimens exist which exhibit modifications embracing both these forms.

The type specimen of *Oracanthus minor,* Ag., which forms a part of the Jones Collection in the Museum of the Geological Society, at Burlington House, is also from the Armagh Limestone. Except a quarter of an inch of the upper extremity the actual specimen has not been preserved, and there is only its impression on the matrix left. It is represented in the "Recherches sur les Poissons Fossiles," Vol. III., Plate iii., fig. 5. It is quite different in form to the other species already mentioned, and the small portion preserved is not only tuberculated, but very distinctly striated, the striæ being parallel with the length of the spine, and the tubercles situated in the grooves between the ridges. The latter feature distinguishes it from Oracanthus, and the general appearance of the spine appears to indicate a near, if not identical, relationship with Asteroptychius, Ag. From the above, it may be gathered that the species of the genus Oracanthus, depending, as they do, on the characters of the surface ornament, are not of sufficent stability to justify retention, and that one species, *O. minor,* Ag., must be eliminated from the genus.

Having thus briefly reviewed the position with regard to the hitherto described species of Oracanthus, it is proposed to suggest a reconstruction of the genus, which will, in all probability, entail its removal from the Plagiostomata and its inclusion in the Placodermic Ganoids.

The figures on Plate LXII., represent a series of specimens, all obtained from the

Armagh limestone, which have external ornamentation more or less characteristic of Oracanthus. They are of varied form, but all agree in being thin osseous plates, whose surface is raised so as to form smooth enamelled pustulations similar to, but smaller than, those on the surface of the Armagh specimens named by M. Agassiz, *Oracanthus confluens.* Amongst this group must be included the examples named by Prof. M'Coy, *Coccosteus carbonarius, Asterolepis verrucosa,* and *Platycanthus isosceles.* That this group of specimens formed the cephalic covering of some fish there can be little doubt. Figures 1 and 2 probably formed the central dorsal shield; figs. 4 and 7, the maxilla and mandible respectively; figs. 5 and 6, the operculum or cheek plates; fig. 12 has the form of a jugular plate, and fig. 13, an external bony plate, bent at right angles. The upper triangular portions of the plate represented in fig. 2, broken or separated from the general mass, have been labelled *O. minor*, and what appear to be similar fragments have been considered by American Palæontologists as representing a separate genus, Pnigacanthus. The specimens so named in the collection of Lord Enniskillen are quite different from the type of the species described and figured by Prof. Agassiz; the latter as already observed, does not possess the characters of the genus. In addition to those specimens which are represented on Plate LXII. there is a large number worthy of very careful study, for the most part similar in form and characters to those figured, but frequently differing in detail, especially as to form.

Three specimens, from the extreme peculiarity of their form, call for especial attention. They are apparently similar to each other and may have been the counterpart organs of three individuals. The largest and most perfect specimen is 14 inches in length, the basal termination absent. The specimen consists of a long shaft, compressed from back to front, slightly arched longitudinally. Its greatest lateral diameter is about an inch towards the basal extremity, antero-posteriorly it is between ·25 and ·5 of an inch. Nearer the upper extremity of the specimen the diameter slightly and gradually decreases until about 2 inches from the extremity where it suddenly expands to 1·75 of an inch, and forms a more or less spatulate expansion, ending with a broadly rounded margin. The specimen is composed of a close-grained, fibrous, osseous substance; one of the specimens shows an internal cavity near the basal end, it is small and conforms generally to its outer surface; the spatulate extremity appears to be a solid bony structure. The outer surface is convex, and ornamented with pustulate tubercles, sometimes indiscriminately scattered over the surface, and at others a short distance apart, assuming a more or less definite arrangement in gyrating lines; the tubercles appear quite similar to those of the external covering of other parts of the fish, that is, assuming that the dermal plates already mentioned belong to the same species. The inner surface of the bone is smooth or striated longitudinally with a concavity corresponding to the outer convexity. The lateral portions formed by the contact of the anterior and posterior surfaces are acutely angular.

The outer or anterior portion of the spatulate extremity is much worn, apparently by abrasion during the life of the fish (see figs. 3, 4, on Plate LXV.)

Along with the numerous examples of the external covering alluded to above, there is in the Armagh limestone a number of ichthyolithes, which were considered by Prof. Agassiz and others, as the spines of *Orthacanthus confluens*. On Plate LXIII., figures 1, 2, 3, three of these specimens are represented so as to indicate some of their peculiarities. They are laterally much compressed, more or less triangular in outline, with one side longer than the others, the junction of the two shorter forming a right angle. It will also be noted that the specimens are in some cases dextral, in others sinistral, and it may be inferred from this that they were probably associated in pairs. The outer surface is covered with considerable uniformity by a more or less irregularly distributed series of pustulate tubercles, smooth and apparently worn at the apex, with radiating ridges descending therefrom, and absorbed in the interspaces forming the general mass of the bone. The tubercles extend across the surface parallel with the open or basal extremity, seeming to indicate successive lines of growth. When these rows of tubercles are followed from the front to the back of the specimen it is observed that they are continuous and extend evenly and around its surface, but that on the lateral surface the rows are rapidly diverted towards the pointed apex, whilst on the posterior surface the lines of tubercles arch still more in the direction of the point. This characteristic is well shown in Plate LXIII., figs. 1, 1a. The basal orifice, which is extremely large, conforms to the outline indicated by the rows of tubercles, the anterior or outer surface extending much lower than the posterior or inner one. The walls are very thin and the internal cavity extends nearly to the point.

As already stated these cone-like ichthyolithes have existed in pairs, and it appears probable that they formed the posterior termination of the body. From the extension of the hard external covering on one side to a much larger extent than the other, it may be inferred that those sides with least covering were in juxtaposition and formed the axis of the body from which the two armour-plated prolongations were expanded. Should this have been the arrangement, the vertical thickness of this portion of the fish appears to have been considerably greater than the lateral.

It is not proposed to treat more fully of this part of the subject at present, but rather to leave for future opportunity, with the hope of increased material, the elucidation of what now appears to be a somewhat difficult problem in fossil ichthyology. All the specimens hitherto mentioned are from the Mountain Limestone of Armagh, and are in the collection of the Earl of Enniskillen.

The specimens of Oracanthus from the Mountain Limestone of Bristol, are longer in proportion to their diameter across the base than those of Armagh, the average length being double the diameter, whilst in those from Armagh the length is about equal to the greatest breadth. In other respects they are similar. A specimen,

slightly imperfect along the inferior or shorter lateral margin is represented on Plate LXIV.; figure 1a, represents the anterior face, and fig. 1, the posterior, the shortness of the latter in comparison with the former, and the convolutions of the rows of tubercles are well shown in this specimen. Two sections are also given; fig. 1c, represents a longitudinal section, and exhibits the thin, compressed antero-posterior form, whilst fig. 1b, serves to show its form a short distance from the basal extremity. It is possible that the two forms from Bristol and Armagh, may indicate sufficient differences to constitute separate species, but until further information as to the general character of the whole fish be obtained, it may be better to regard them as modifications only of one species. The Bristol specimens are also in the Earl of Enniskillen's Collection.

The Museum of the Geological Society at Burlington House, contains two specimens of this genus of very large size. The locality from which they have been derived is not known. One of the specimens is preserved to the length of sixteen inches from the apex downwards, and the base, which is seven inches wide at the lowest part preserved, is broken and imperfect, and in all probability may have been several inches longer. The second specimen is also imperfect, it is represented on Plate LXIV., fig. 2, the part preserved is ten inches in length, and the base about seven inches wide, its width converges rapidly to about 3 inches, the remaining portion of the apical extremity is broken off. Both specimens are extremely flat and compressed, they are cracked and broken in several places, so that the flatness may be in a great measure owing to the instability of the extremely thin walls which are little more than the eighth of an inch in thickness. The bony substance of which they are composed is fibrous and has a strong tough appearance; the surface is coarsely pitted in the spaces between the rows of tubercles, the latter are prominent, enamelled and smooth, and for the most part connected together so as to form long parallel ridges ·25 of an inch apart. The under surface of the bone is smooth or striated longitudinally. The internal orifice is, of necessity, only about a quarter of an inch smaller than the external diameter.

These specimens do not differ in any important particular, except in size, from those of Bristol or Armagh.

Formation and locality: Mountain Limestone, Armagh.
Ex. coll. Earl of Enniskillen.

Genus.—Stichacanthus, L. G. de Koninck.

Stichacanthus—L. G. de Koninck, 1878. "Fauna du Calcaire Carb. de la Belgique," p. 70.

Professor de Koninck designates under this generic name species of tolerably large size, having the form of a recurved and depressed horn with a tolerably strong base. The surface is covered with a numerous series of longitudinal and parallel nodular ribs. The tubercles are prominent, somewhat elongated and attached the one to

the other by the prolongation of the ribs upon which they are fixed. The interior of the spine is hollow almost to the summit, and the walls are thin. The posterior margin is armed with small spines directed obliquely towards the base.

This genus has frequently been associated in collections with (so-called) Oracanthus, to which in some respects the specimen now to be described bears a resemblance. Its walls are thin, with large internal cavity, the long slender form of this genus is, however, quite distinct from the triangular and irregular outline of Oracanthus and the tubercles instead of being arranged as in that genus, are placed in regular longitudinal rows. Prof. de Koninck suggests a resemblance to Physonemus of M'Coy, it appears to be a very superficial one in the present case.

Stichacanthus tortworthensis, Davis.

(Pl. LXV., fig. 2.)

Spine, medium size, long and comparatively slender, gently arched, much compressed, imperfect, basal and apical terminations absent—part preserved is eleven inches in length—greatest width near base 2·3 inches, gradually diminishing to ·8 of an inch at the part nearest apex which is preserved. A transverse section is oval, laterally compressed or flattened, the anterior and posterior extremities of the section being more or less pointed. The surface is ornamented by a numerous series of longitudinal ridges, decreasing by inosculation as they approach the apex. The ridges extend parallel for the most part with the concave (posterior?) margin. The ridges are produced at short intervals so as to form nodular tubercles, broadly implanted, rounded and smooth at the top. The ridges are separated by longitudinal furrows, which are again subdivided by minute striations especially towards the basal extremity. The walls of the spine are thin, and the internal cavity large. The basal portion which may have been implanted in the body of the fish is not preserved. Along the convex margin of the spine the tubercles are larger than on the sides, and present the appearance of denticles: the tubercles on the concave margin do not present any special feature.

This species differs from *Stichacanthus cœmansi*, de Koninck, by its length being considerably greater in proportion to its diameter at the basal extremity; in the smaller size of the dermal tubercles, the longitudinal ridges being narrower and more numerous; and in the subdivision of the ridges by striæ.

I have ventured to designate this species by the *nomen triviale* derived from the locality where the specimens have been found, which was in the immediate vicinity of Tortworth Court, the seat of the Earl of Ducie, to whom I am indebted for the opportunity of describing the specimens included in this genus, and the great spine for which I have been obliged to establish the following genus.

Formation and locality: Mountain Limestone, Tortworth.

Ex coll. Earl of Ducie, Tortworth Court.

Genus.—Phoderacanthus, Davis.

Spine, very large size, strong, gently and gracefully arched, wide at the base, gradually tapering to an acute apex; transverse section, more or less oval, compressed laterally towards the basal extremity, internal cavity wide, opening terminally; posterior cavity or groove absent, no posterior denticles; surface uniformly covered with large smooth tubercles arranged on longitudinal ridges and also to a greater or less extent forming lines across the spine. Osseous walls of the spine pierced by several cylindrical canals extending longitudinally parallel with the surface. Base not preserved.

The magnificent specimen which forms the type of this genus, is perhaps the largest example of a fin-defence hitherto discovered. The imperfection of the base renders necessary an addition of at least several inches to its length, and there is thus indicated a truly formidable and terrible weapon of offence, nearly or quite three feet in length.

The genus Antacanthus, Dewalque, in several respects appears to possess characters similar to those of the genus now described. They resemble each other in the arrangement of the tubercles on the surface and in the possession of large cylindrical canals in the mass of the bony structure of the spines, but there is a great divergence in the form of the transverse section of the spines of the two genera; in the absence of large denticular tubercles on either the convex or concave margin of this one; and above all in the character which gives the name to the genus Antacanthus. Prof. de Koninck considers that the direction of the line dividing the exposed from the embedded portions of that species, showing its oblique implantation in the body, the line of demarcation forming an obtuse angle with the convex surface of the spine, and an acute angle with the concave surface which is the opposite of the arrangement in such genera as Ctenacanthus or Gyracanthus, indicates that the convex margin was the posterior one, and the concave the anterior one. The genus now introduced does not appear to diverge from the ordinary types of plagiostomous fishes, though the basal extremity of the spine is wanting, the rows of tubercles, already described as extending *across* the spine, no doubt indicate the line of demarcation to a large extent, and this being so, it is evident, that the line would form an acute angle with the convex border, and an obtuse one with the concave in the ordinary way.

With the genus Oracanthus, with which this specimen has been erroneously associated to the present time, it possesses little in common except its pustulate surface; and in the character of the pustulations a comparison of the two will prove that they are quite distinct. The long comparatively slender and graceful form of this genus, its thick convex walls, and arched form, are altogether different from the thin compressed section of Oracanthus, with its great basal opening and rapidly converging antero-posterior margins. In the peculiar duplicate arrangement of the spines (?) of Oracanthus, there is a still greater divergence from anything analogous in the form of this genus.

Phoderacanthus grandis, Davis.

(Pl. LXV., fig. 1.)

Oracanthus pustulosus—MS. in Collection of the Earl of Ducie.

Spine, very large, massive and strong, gracefully arched, devoid of posterior cavity, or external groove. Imperfect at the basal extremity and exhibits no basal surface indicating the extent of its insertion in the integument of the body. The length of the part preserved is 27 inches; the diameter near the base is 5 inches, it gradually decreases towards the apex ending in a point. The surface of the spine is much fractured and broken, but sufficient remains intact to show the nature of its ornamentation. Transverse section more or less oval, inferior margin rotund, lateral ones convex, gradually converging to form a superior margin slightly less rotund than the inferior one. Near the apex the section is much less compressed than it is near the base, the latter appearing to be somewhat crushed. The internal cavity is large and conforms generally to the external surface. The walls of the spine are about ·5 of an inch in thickness, except on the superior margin where they are somewhat thicker. The surface of the spine has been uniformly ornamented with a series of pustulate ridges, extending in longitudinal rows; the pustulations also extend in close lateral contiguity one with another forming a continuous, somewhat wavy ridge across the spine, less regular and slightly smaller near the apex than below. The pustulations are smooth, prominent, broadly and firmly implanted in the body of the spine. There is no distinct evidence of either superior or inferior margin having possessed any denticular processes larger than the pustulations occupying the general surface.

The osseous substance of the spine is hard, compact and fibrous. It is pierced by longitudinal cylindrical canals which appear to have served the purpose of conveying the nutrient juices from the base towards the apex of the spine. The most prominent and largest of these canals is situated midway between the external surface of the superior margin and the large internal cavity; it is ·1 of an inch in diameter; others occur in the substance of the spine, along the lateral margins and may be distinctly recognised in several places where a portion of the outer surface of the spine has been removed.

M. de Koninck, in the description of *Antacanthus insignis,* Dewalque, from the black limestone of Liege ("Fauna du Calcaire Carb. de la Belgique," p. 74), notes the passage of a cylindrical canal in that species similar to the one described above in the superior portion of the spine, but he does not mention others.

Formation and locality: Mountain Limestone, Bristol.
Ex coll. Earl of Ducie, Tortworth Court.

3. Description of Localities.

Before giving a detailed description of the several localities in the British Islands in which the Carboniferous Limestone has been proved to contain remains of fossil fishes, it may be worth while to briefly summarize what is known of the general character and constitution of the formation as a whole. In Derbyshire the limestone is a pure, thick-bedded and massive rock, probably two or three thousands of feet in thickness with occasional but very thin beds of shale. Similar characters prevail in the neighbourhood of Clitheroe, in Yorkshire, and the limestone has been estimated to attain even a greater thickness than in Derbyshire. northwards and southwards of these localities the limestone becomes much thinner and gradually assumes a different character. The massive limestone of Derbyshire is diminished southwards in Leicestershire to little more than two hundred feet in thickness and is intercalated with thick beds of shale; still further southwards the coal measures of South Staffordshire rest immediately on the silurian rocks, and the Carboniferous Limestone is entirely absent. From Clitheroe northwards the limestone diminishes in thickness to 600 feet beneath Ingleborough and a few miles further, in Wensleydale, has lost its thick-bedded character and is divided into a number of beds of thin limestone with numerous intervening strata of shale and sandstone, whilst in Northumberland, still further northwards on the southern flank of the Cheviot Hills, the shales and sandstones have increased to an enormous thickness and the limestone has almost entirely disappeared, represented only by a few thin bands. In Cumberland a similar decadence may be traced, throughout the whole of this district, where the base of the thick limestone has been exposed, it is found to rest unconformably on the upturned or contorted beds of Lower silurian rocks. The junction of the two may be seen to advantage in the neighbourhood of the Great Craven faults in Yorkshire; as for example, at Monghton Fell in Ribblesdale, at Norber or at Thornton Force beneath Ingleborough. The silurian rocks are in all instances bent and folded at a high inclination, the whole denuded down to an even surface on which the limestone is deposited.

In Ireland the Carboniferous Limestone is very largely developed, and consists for the most part of three divisions; there is a thick, pure limestone at the base and the top, and between the two a middle division which is more or less mixed with shales or sandstones, the limestone is also impure and earthy. In the Kilkenny district the limestone is pure and massive, reaching to two or three thousands of feet in thickness. To the southwards and south-westwards it thins out and is gradually replaced by shales in counties Waterford and Cork, and still further to the south entirely disappears, and its place is taken by thick masses of coarse gritstone. Northwards, at Armagh, the limestones are thin and divided by beds of shale and sandstone, and towards the highlands of Donegal

and Connemara, the limestone is interleaved with shales and sandstones, with occasional beds of thin coal. In Ireland as well as England the limestone rests on the denuded edges of silurian grits and slates, sometimes with the intervention of conglomerates or sandstones, sometimes without. In each the limestone is very thick and massive in the central portions of its area, and their northern and southern portions become intercalated with beds of shale and sandstone, which gradually increase in thickness towards the boundary line, the limestone at the same time becoming thinner bedded and finally disappearing.

The Carboniferous Limestone in Scotland occupies the lowland country between the Grampian Mountains and the border hills. The series is divided into two parts—the Lower or Calciferous Sandstones, and the Upper or Carboniferous Lime stone. The former consists of an extremely irregular series of sandstones, shales, limestones, and thin beds of coal, about six hundred feet in thickness. The Carboniferous Limestone series is composed of alternating beds of shale and sandstone, with several layers of thin limestone. The greatest development is at Beith, in Ayrshire, where the limestone is about forty feet in thickness. Beds of clay-ironstone are of frequent occurrence, especially in the upper portions. The Northumberland district resembles that of the Scottish group to a large extent; they are composed almost entirely of sandstones and shales, with occasionally thin limestones and coals.

In the *district around Armagh*, from which the majority of the fish remains described in the preceding pages have been obtained, the Carboniferous Limestone series overlie the grits and slates of Lower Silurian age, the equivalents of the Bala or Carodoc Beds of Wales; the series consists of—

Upper Limestone,
Calp or Middle Division,
Lower Limestone,
Sandstones.
Lower Silurian.

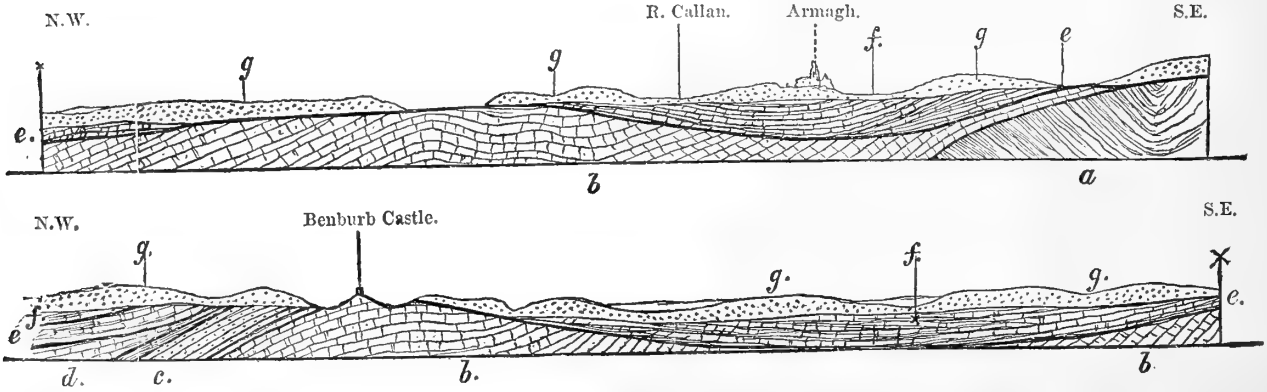


Fig. 1. Section from S.E. of Armagh, to N.W. of Benburb Castle.

a. Silurian strata.
b. Lower Carboniferous Limestone.
c. Calp or Middle Series.
d. Upper Carboniferous Limestone.
e. Permian Beds.
f. Bunter Sandstone.
g. Drift.

Horizontal scale, 1½ inch to 1 mile. Vertical scale, 4½ inches to 1 mile.

The following description of the Mountain Limestone in the *neighbourhood of Armagh,* is derived from the explanatory memoir, sheet 47, of the Geological Survey of Ireland. The Lower Limestone of the Carboniferous series consists chiefly of light gray crystalline limestones, sometimes possessing a slight bluish tinge, and in certain localities assuming a deeper brown and reddish shades. The beds are in most places separated by thin layers of dark gray shale. The limestone is generally highly fossiliferous, many of the beds containing large bunches of coral, crinoidal fragments, shells, and especially towards the base, fish remains. It is from these beds that the typical specimens of the Jones' and Enniskillen Collections have been obtained, as well as the great bulk of the latter magnificent collection now deposited in the New Natural History Museum at South Kensington. Cherty bands are occasionally met with. The thicker beds of limestone supply very good building stone, which has been extensively quarried in some parts. In the neighbourhood of Armagh, some of the lower beds have been worked and polished for marble. These furnish a close-grained rock, which, being of a pinkish or purplish brown and gray colour, beautifully spotted, and clouded with various tints of yellow and brown, and susceptible of a high polish, is well adapted for ornamental work. Some of these beds are flaggy, and have been used in the streets of Armagh. The limestone is in many localities burned for lime of an excellent quality, which is principally used for agricultural purposes. A bluish limestone at Benburb, is said to produce lime possessing hydraulic properties. This was used in the bridges over the Ulster Canal. Occasional beds of yellowish and light reddish silicious sandstone occur in various parts of the district, interstratified with the limestone, and these have in some places been quarried for building.

The Calp consists of sandstones, blue shales and earthy limestones. They are exposed south-west of Benburb. Thin seams of coal occur. The shales are replete with fossils and the sandstones contain remains of plants as well as mollusca. The Upper Limestone in this district is thin, light gray in colour and somewhat arenaceous, and is shown in the section, figure 1 d; a small thickness of gray arenaceous limestones of the upper series is exposed near Benburb.

The Lower Limestones are extensively quarried for building and burning for lime. In a quarry on the west side of the road from Armagh to Loughall, a mile and a quarter south-west of the latter place, the beds consist of thin bands of light brownish compact limestone, with layers of dark reddish sandy shale. Fish remains are found in the latter, and both are largely composed of shells. The largest quarries lie south of Armagh, near Red Barn. About a mile from the city in that direction a quarry contains beds of limestone from one to five feet thick; the rock is a light yellowish or pink colour, and crystalline. Numerous corals with large masses of Lithostrotion occur, crinoid stems and the shells of molluscs are common, and fine specimens of fish remains have been procured. Similar fossils have been obtained in a large quarry near the ancient entrenchment

called Navan Fort, one mile and a half west of Armagh. The face of the rock worked is sixty feet in height. The fish remains are found principally in the upper beds.

At Tullyard, west of Wilson's Bridge, on the Ulster Railway, the Lower Limestone is extensively quarried: the beds dip S.W., at an angle of 30° to 40°. They have the usual character of the limestone in this district, varying from one to three feet in thickness separated by shales. The limestone ranges from a bluish gray to a brown colour, and is mostly of a crystalline texture. It contains numerous fossils.

The Carboniferous Limestone of the *South-eastern portion of Ireland* presents some variations from the series of strata composing the formation around Armagh. It consists mainly of three groups (see the section fig. 2), but the lower Limestone is frequently dolomitized either by the admixture of carbonate of magnesia during deposition or by a subsequent change in its character. The Limestone Series are separated from the Silurian beds by great thicknesses of Old Red Sandstones, attaining in some instances a vertical extent of more than 3,000 feet. These rest unconformably on the Silurian rocks, whilst above the sandstones are an additional 200 feet of shales beneath the base of the limestones. The following is the series as developed in the district around Wexford and Waterford.

Upper Limestone.
"Calp" series.
Lower Limestone (sometimes Dolomitic.)
Lower Limestone Shale.
Upper Old Red or "Yellow Sandstone."
Old Red Sandstone.
Lower Silurian Beds.

The Old Red Sandstone is composed for the most part of breccias and conglomerates of well-rounded pebbles of grits, slates and quartz cemented together, with occasional thick beds of shale and sandstone of a reddish-brown colour. Above these are the yellow sandstones separated by an arbitrary line, indicated by a change in colour; they vary from 200 to more than 500 feet in thickness. Occasionally the remains of plants are found in the shales of the Yellow Sandstone series.

The uppermost beds of the Yellow Sandstone series at Hook point pass gradually into the Lower Limestone shales, and from them into the Lower Limestone. The yellow and greenish sandstone and shales change to dark gray, sandy, calcareous shales and thin grits, alternating with occasional seams of black chert and impure gray limestone. These are followed by limestones, and in a thickness of about 200 feet the shales and sandy portions disappear altogether. The beds are throughout fossiliferous, Spirifer, Orthis and Strophonema, Encrinites and Fenestella serving to distinguish the beds of Carboniferous age. The Lower Limestone is generally crystalline, thick-bedded, regularly jointed, and of a dark gray colour. In some

localities the rock is more or less flaggy, as at Granny Castle and Dunkitt, N.W. of Waterford, where there are large quarries. It also changes to a dolomitic or magnesian limestone, and where this has occurred the limestone becomes of a pale brown colour and saccharoid texture; it loses its bedding and all traces of fossils disappear. The thickness of the Lower Limestone is estimated at not less than 700 feet.

Several species of fossil fishes have been found in the Lower Limestone of Hook Point and besides these, a greater variety of fossil mollusca, encrinites, and corals than is to be found in many localities. Mr. W. H. Baily, Palæontologist to the Irish Geological Survey, gives this description of the limestone and its fossils:— "Nothing can exceed the beauty of these fossils where the beds are exposed and weathered, as they are nearly all round the shores of this point. The rocks of dark, nearly black limestone are almost horizontal, and rise by a succession of steps from the sea, with great fissures or joints interrupting the continuity of the beds. The surfaces of these beds are crowded with Corals, Polyzoa, Brachiopods, and Crinoids, and sometimes fish-remains. The delicate network of the Reteporidæ, and elegant structure of other kinds of Polyzoa, with the internal arrangement of the Brachiopod shells and the graceful Crinoids, with stems, arms, and heads attached, are all displayed in perfection at this favourite locality; and I know of no other place where such a fine field is open for investigating the structure of these particular groups of fossils *in situ* as this place affords."

The Middle Limestone or "Calp" is composed of compact, evenly-bedded limestone, dark gray or black in colour, with occasional layers and nodules of black chert and beds of earthy shale, they are occasionally finely crystalline and reach 500 feet in thickness. The Upper Limestones are generally similar in character but of a light gray colour, and contain white chert as well as black. North of Clonmel this group is about 400 feet in thickness.

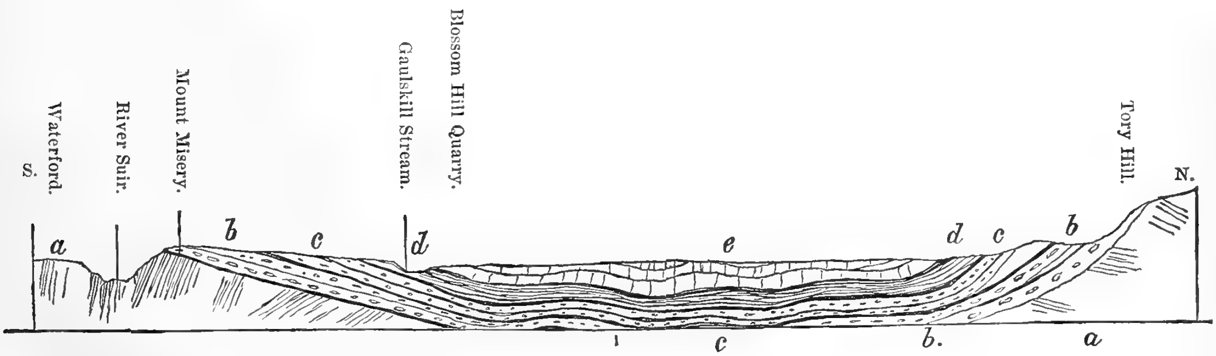


FIG. 2. SECTION FROM WATERFORD, NEAR DUNKITT, TO TORY HILL.

a. Silurian Rocks.
b. Old Red Sandstone.
c. Yellow Sandstone.
d. Lower Limestone Shale.
e. Lower Limestone.

Horizontal Scale, 1 inch=1 mile. Vertical Scale, 3 inch=1 mile.

Bristol.—The Carboniferous Limestone in this district underlies the Bristol Coal-field, and rests conformably on the marls and sandstones of the Devonian or Old Red formation. It consists of the following members:—

Millstone Grits and Coal Measures.
Upper Limestone Shales.
Carboniferous Limestone.
Lower Limestone Shales.
Old Red Sandstone.

The junction between the Old Red Sandstone and the lower beds of the Limestone Shales is an almost imperceptible one, and can only be discriminated by the gradual insertion of thin beds of calcareous shales and the presence of fossils of purely Carboniferous types. The section exposed on the banks of the Avon, near Bristol, exhibits the whole series as developed in Somerset and Gloucestershire, and as it is from the quarries near the river that nearly all the fossil fishes have been obtained, a short description of the Avon section may serve the purpose at present in view.

The north-western extremity of the section, near Cook's Folly, is composed of Devonian sandstones and marls of a red colour. Towards the upper part a quartzose conglomerate occurs, and about thirty feet above this is the first bed which exhibits a decided admixture of carbonate of lime. The base of the Lower Limestone shale series may be placed somewhere between the two, though it is quite impossible to determine its exact position. The limestone shales are about 500 feet in thickness, and are throughout more or less fossiliferous. They consist of shales with thin beds of limestone. About 100 feet from their base there is a thin breccia four or five inches in thickness; when freshly broken it has a grayish brown colour, which quickly changes by exposure to dark reddish brown from the oxidation of the iron it contains. The breccia is replete with fossil fish palates, and some coprolites have been found which contain the comminuted remains of the hard coverings of mollusca. Numerous shales and limestones with characteristic fossils occur between the breccia and a second stratum, which is remarkable for the presence of remains of Oracanthus associated with remains of Brachiopods. The bed is an argillaceous limestone which weathers easily, and the fossils are in consequence more easily and perfectly separated from the matrix. It is nearly 200 feet above the breccia, and about the same depth below the Carboniferous Limestone proper. The latter attains a thickness, in the Avon section, of 2,000 feet, and may be studied in the Black Rock and Great Quarries. The change from the lower shales to the thick limestone is very gradual, and it is impossible to draw a distinct line of demarcation between the two. The limestone in the Black Rock Quarry is very dark in colour, due to the presence of bitumen. The latter is occasionally so abundant as to be distinctly recognised by the smell. The strata are very regularly and uniformly bedded, dipping at an angle between 20° and 30° to the S.S.E. In the Black Rock Quarry, about 100 feet above the base of the

limestone, are three beds which are easily distinguished by their remarkably parallel and symmetrical arrangement. These are the fish-beds of the limestone, as distinguished from those already mentioned in the Lower Shales. It is from these beds that the magnificent spines of *Ctenacanthus major*, Ag., have been obtained; the great teeth of Psammodus and numerous others have also been found here. Beyond the fish-beds a number of interesting beds occur, a series, about 167 feet in thickness, are Oolitic in structure. The limestone in the Great Quarry is a lighter gray in colour; between the beds there is frequently a deposit of crystals of fluor spar.

Above the thick limestone there are about 400 feet of upper limestone shales which pass gradually into the millstone grits, 1,000 feet in thickness.

The following section exhibits the series of strata between Cook's Folly and the Black Rock Quarry :—

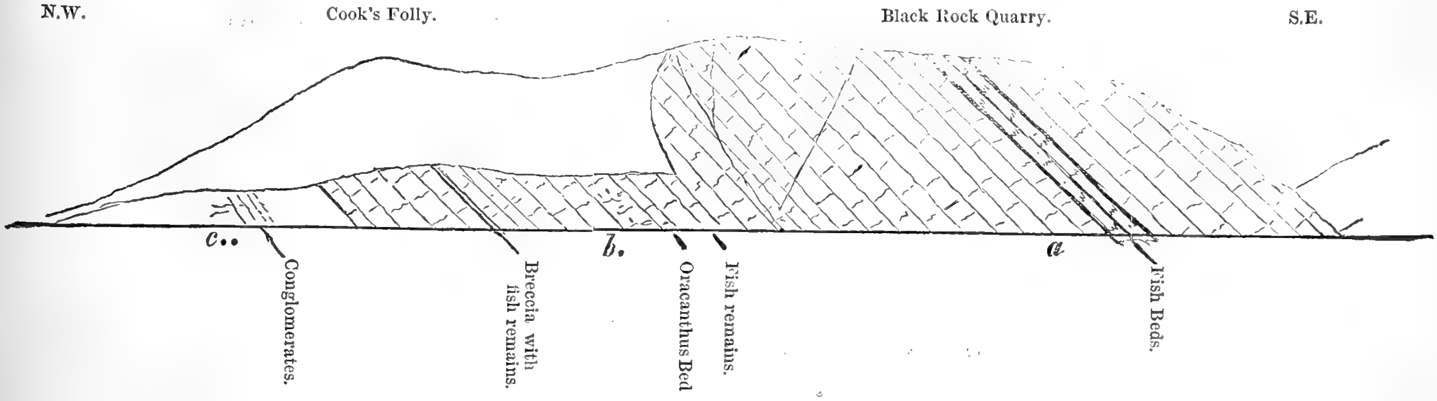


Fig. 3, Section in the Avon Valley, near Bristol.

a. Mountain Limestone. *b.* Lower Limestone Shales. *c.* Old Red Sandstone.

The *Farlow and Oreton* Limestone forms an outlier of small extent at Titterstone, Clee Hill, in Shropshire. The hill rises from a depression of the Old Red Sandstone near Cleobury, and its flanks exhibit the whole of the Carboniferous series as developed in that district. Above the Old Red Sandstone are the Carboniferous Shales and Limestone, surmounted by the Millstone Grits and Coal Measures, which are capped by a considerable mass of basalt which has been forced by volcanic action through the entire series and overflowed the top of the hill. The following sketch from Murchison's "Siluria" very clearly exhibits the series :—

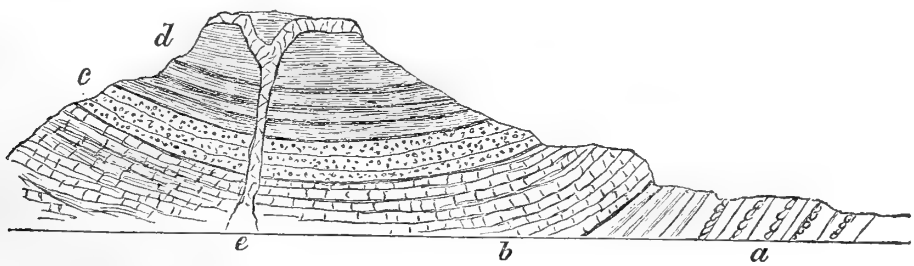


Fig. 4, Section across Litterstone, Clee Hill, Shropshire (after Murchison).

a. Old Red Sandstone.
b. Carboniferous Shale and Limestone.
c. Millstone Grit.
d. Coal-measures.
e. Erupted basalt.

The thin beds of limestone forming the base of the Titterstone Clee coalfield are continued in a north-easterly direction, and well exposed at Oreton and Farlow. The Carboniferous Limestones there overlie a series of yellow sandstones which constitute the upper beds of the Old Red series. At Oreton the limestone is extensively quarried, and affords good sections of the general thickness and character of the limestone. The beds are thicker than at Farlow half a mile distant, though the arrangement is the same. The middle and lower portions of the limestones are the most fossiliferous. The principal fossil remains are those of Brachiopods, Spirifer and Rhynconella being most abundant. Bryozoan remains are numerous and those of Crinoids and a Crustacean have been found. The most important remains, however, are those of the fishes, which have been described in preceding The fauna indicates a deep-sea condition.

The series of Oolitic Limestones exhibit similar structural agencies in their formation to those of the Carboniferous Limestone of Bristol, and that of the margin of the South Wales coalfield. The "Jumbles" or Clee Hill marble, has been worked for decoration purposes, it is the thickest of the Oolitic beds. The accompanying sketch (fig. 5), will exhibit the relative position of the beds in the Oreton and Farlow district. The fish remains were got from the gray Oolitic Limestone near the base of the section.

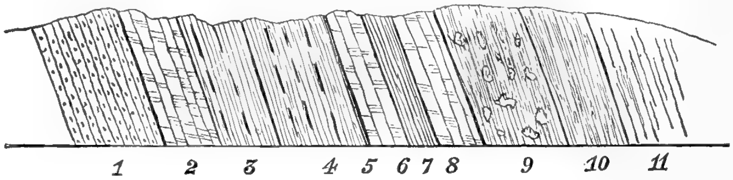


FIGURE 5.

SECTION showing the MOUNTAIN LIMESTONE at FARLOW, in SHROPSHIRE (from Morris and Roberts).

1. Yellow Sandstone with concretionary masses of Limestone.
2. Gray Oolitic Limestone (from which large palatal teeth were got), 3 feet 6 inches.
3. { Sandrock with nodules of calc spar, 2 feet. Gray Oolite Limestone (Jumbles), 4 feet 6 inches.
4. Soft sandy rock and clays with feruginous beds, 4 feet 6 inches.
5. Black clay, 4 inches.
6. Gray Limestone, very shelly, 1 foot.
7. Brown clays 2 feet, dip about 60° S.E.
8. Gray crinoidal Limestone, with bryozoa, 4 feet 6 inches.
9. Dark gray clays with concretionary Limestone, 6 feet.
10. Sandy beds with thin beds of Limestone, 3 feet.
11. Thin bedded bands of sandy Limestone, with concretions of argillaceous Limestone.

Derbyshire—The Mountain Limestone in Derbyshire is generally a pale gray, thick-bedded and massive deposit of carbonate of lime, it contains a few partings of shale and clay, and some beds of volcanic origin called "toad-stone." Its base has never been reached, but its thickness is estimated at 4,000 to 5,000 feet. The limestone occupies a large extent of surface, reaching from Bakewell to

Buxton, Matlock and Castletown. Above the limestone there is a series of shales and gritstones, about 500 feet in thickness, which are the equivalents of the Yoredale series of Wensleydale. It is principally from the black shales immediately overlying the thick Mountain Limestone, that the remains of fishes are obtained in this district. In no instance are they plentiful.

In Yorkshire the Mountain or Carboniferous Limestone is very largely developed, attaining its greatest thickness in the district around Clitheroe. It is there extensively quarried, and the remains of mollusca, bryozoa, and encrinites are abundant but fish remains have not been found ; at Skipton one or two examples of the teeth of Lophodus have been discovered, and at Settle, where the limestone is exposed along the line of the Craven fault, and quarried, the teeth of several species of fishes have been discovered. The principal locality in Yorkshire, however, is near Leyburn, in Wensleydale, in the uppermost beds of the formation. It has already been observed that the thick-bedded, massive limestone of the districts named above, as they extend northwards, become divided by the interlamination of wedge-shaped beds of shale and sandstone into several thinner beds, forming a somewhat complex series to which the late Prof. Phillips applied the term "Yoredale Series." The following section gives approximately the series as it occurs in Wensleydale :—

Millstone Grit Series,	— feet.
Red Limestone,	20 to 40 feet.
Shale,	—
Main Limestone,	60 feet.
Grits, Coal and Shale,	80 ,,
Underset Limestone,	30 ,,
Laminated Grits, flagstones and shale, with band of impure productal limestone,	350 ,,
Middle Limestone,	30 ,,
Gritstones and flags,	150 ,,
Simonside Limestone,	20 ,,
Flags, Shales and Grits,	100 ,,
Hardrow Limestone,	40 ,,
Grits, Shales and Ironstone,	100 ,,
Lower massive or Scar Limestone (exposed),	250 ,,

The uppermost limestone, locally named "Red Beds," is the one from which a very large majority of the fossil fish remains have been obtained, which are known to occur in the Yorkshire beds. A few have been found in the main limestone of the same district.

In Northumberland the Carboniferous Limestone formation becomes still more divided into alternations of limestone, sandstone and shales than in the north of Yorkshire. It lies, without the intervention of the Old Red Sandstone series, on the contorted and denuded edges of the Silurian rocks. The strata of Carboniferous age, beneath the millstone grits have been divided into two groups ; the lower,

named by Mr. G. Tate, the Tuedian, consists of red sandstone conglomerates, surmounted by red sandstones, and above them beds of limestone, shales, and clays, the uppermost bed being the Dun or Lamberton limestone, the whole are about 1,500 feet in thickness. The Upper group, several thousands of feet in thickness, for which the name Bernician beds has been suggested by Prof. Lebour, occupy a large area in the western part of the county, extending from the Cheviot hills and the sea coast at Berwick and Alnmouth, southwards to Hexham. The Bernician beds are the equivalents of the Yoredale rocks of North Yorkshire and the thick-bedded scar limestone of Settle and Derbyshire. The Yoredale series in their progress northwards are largely developed. Thick massive grit rocks are intercalated with numerous beds of light bluish grey limestone, thick beds of shale and thin seams of coal. Fossils, principally mollusca of the ordinary Mountain Limestone species, are numerous throughout the limestones; crinoids and foraminifera are not uncommonly met with. The "four fathom limestone" and the "great limestone" are extensively quarried at Lowick and along with a great number of species of invertebrates, several species of fish have been discovered.

The Carboniferous Limestone series of the west of Scotland assume an entirely different arrangement to that of the beds in England or Ireland. The massive Scar Limestone is absent and a large portion of the beds are of fresh water or brackish origin. The following is the sequence of the beds beneath the Millstone grits :—

Upper Limestone Series.
Lower Coals and Ironstones.
Lower Limestone Series.
Calciferous Sandstone Series.
Old Red Sandstone.

The Upper Limestone Series are between 500 and 600 feet in thickness and consist principally of thick sandstones, shales, clay ironstones and coals, with several beds of impure limestone; organic remains are abundant, consisting principally of mollusca, crinoids, foraminifera, corals, polyzoa and some fish remains. The Lower Coals and Ironstone are nearly related in lithological characters with the Upper Coal Measures. They are, with slight exceptions, of freshwater or terrestrial origin, consisting of sandstones, numerous bands of clay ironstone, shales and coals. The Lower Limestone Series most nearly approaches the Mountain Limestone in palæontological characters. It ranges from 600 to more than 1,000 feet in thickness and its lithological character is somewhat similar to that of the Upper Limestone Series at Beith in Ayrshire, some of the beds of limestone attain a thickness of more than 40 feet, but generally they are much thinner. One or two workable beds of coal, and numerous bands of clay ironstone, occur in several horizons of the strata. In some districts, as at Campsie, thin beds of estuarine, or

freshwater limestone, containing ostracoda and other organisms belonging to species that occur in the Upper Coal Measures, alternate with the coal beds and marine limestone. The fossils of the marine limestones and shales are numerous, and consist of plants, foraminifera, sponges, corals, crinoids, crustacea, polyzoa, shells and fish remains.

The Calciferous Sandstone Series are 1,500 to 1,800 feet in thickness and consist in the upper division of a great thickness of bedded traps and ash beds, on which occur occasional beds of sandstone, impure coal and shale, enclosing plant and fish remains. Conformably with the ash beds, in descending order, are the Ballagan Limestone series, consisting of numerous dolomitic limestones, greyish white sandstones, flaggy sandstones, shales and marls, which contain remains of plants and occasional fish scales which indicate fresh water origin. Beneath the Calciferous Sandstones are the Old Red Sandstones.

4. List of Genera and Species, with Localities.

Name.	Armagh (Ireland).	Bristol.	Salop, Oreton, and Farlow.	Yorkshire.	Derbyshire.	Kendal, Westmoreland.	W. Scotland.	Lowick, N.W.
HYBODONTIDÆ.								
Ctenacanthus major, Agass.,	–	×	×	–	–	–	×	–
,, tenuistriatus, Agass.,	–	×	×	–	–	–	×	–
,, heterogyrus, Agass.,	×	–	–	–	–	–	–	–
,, brevis, Agass.,	×	×	×	–	–	–	×	–
,, denticulatus, M'Coy,	×	–	–	–	–	–	–	–
,, limaformis, Davis,	×	–	–	–	–	–	–	–
,, salopiensis, Davis,	–	–	×	–	–	–	–	–
,, dubius, Davis,	×	–	–	–	–	–	–	–
,, lævis, Davis,	×	–	–	–	–	–	–	–
,, plicatus, Agass.,	×	–	–	–	–	–	–	–
,, sulcatus, Davis,	–	×	–	–	–	–	–	–
,, pustulatus, Davis,	×	–	–	–	–	–	–	–
,, crenulatus, Agass.,	×	–	–	–	–	–	–	–
,, (Onchus) rectus, Agass.,	×	–	–	–	–	–	–	–
Acondylacanthus Colei, Davis,	×	–	–	–	–	–	–	–
,, tuberculatus, Davis,	×	–	–	–	–	–	–	–
,, (Ctenacanthus) distans, M'Coy,	×	–	–	–	–	–	–	–
tenuistriatus, Davis,	×	–	–	–	–	–	–	–
,, (Leptacanthus) junceus, M'Coy,	–	–	–	–	×	–	×	–
,, Jenkinsoni, M'Coy,	–	–	–	–	–	–	×	×
attenuatus, Davis,	×	–	–	–	–	–	–	–
Asteroptychius ornatus, Agass.,	×	–	–	–	–	–	–	–
Compsacanthus carinatus, Davis,	×	–	–	–	–	–	–	–
Cosmacanthus marginalis, Davis,	×	–	–	–	–	–	–	–
,, carinatus, Davis,	–	–	–	–	–	–	–	–
,, carbonarius, M'Coy,	×	–	–	–	–	–	–	–
,, priscus, Davis,	×	–	–	–	–	–	–	–
Lispacanthus retrogradus, Davis,	×	–	–	–	–	–	–	–
,, gracilis, Davis,	×	–	–	–	–	–	–	–
Dipriacanthus Stokesii, Agass.,	×	–	–	–	–	–	–	–
Homacanthus microdus, M'Coy,	×	–	–	–	–	–	×	–
,, macrodus, M'Coy,	×	–	–	–	–	–	–	–
Gnathacanthus triangularis, Davis,	×	–	–	–	–	–	–	–
,, striatus, Davis,	×	–	–	–	–	–	–	–

TABLE—*continued.*

Name.	Armagh (Ireland).	Bristol.	Salop, Oreton, and Farlow.	Yorkshire.	Derbyshire.	Kendal, Westmoreland.	W. Scotland.	Lowick, N.W.
Cladacanthus paradoxus, Agass.,	×	–	–	×	–	–	–	–
,, major, Davis,	×	–	–	–	–	–	–	–
Physonemus armatus, M'Coy,	×	–	–	×	–	–	×?	–
,, subteres, Agass.,	×	–	–	–	–	–	–	–
,, attenuatus, Davis,	×	–	–	–	–	–	–	–
,, hamatus, Davis,	×	×	–	–	–	–	–	–
Chalazacanthus verrucosus, Davis,	×	–	–	–	–	–	–	–
Cladodus mirabilis, Agass.,	×	×	–	×	×	–	×	–
,, marginatus, Agass.,	×	–	–	–	–	–	×	–
,, elongatus, Davis,	×	–	–	–	–	–	–	–
,, striatus, Agass.,	×	–	–	×	×	×	×	×
,, curvus, Davis,	×	–	–	–	–	–	–	–
,, destructor, Davis,	×	–	–	–	–	–	–	–
,, acutus, Agass.,	×	–	–	–	–	–	–	–
,, Milleri, Agass,	–	×	–	–	–	–	×	–
,, conicus, Agass.,	–	×	–	–	–	–	×	–
,, basilis, Agass ,	×	–	–	×	–	–	–	–
,, Hornei, Davis,	–	–	–	×	–	–	–	–
,, mucronatus, Davis,	–	–	–	×	–	–	–	–
Carcharopsis Colei, Davis,	×	–	–	–	–	–	–	–
Pristicladodus dentatus, M'Coy,	×	–	–	×	×	–	×	–
,, concinnus, Davis,	×	–	–	–	–	–	–	–
,, Goughi, M'Coy,		–	×	×	–	×	–	–
Glyphanodus tenuis, Davis,	–	–	–	×	–	–	–	–
ORODONTIDÆ.								
Orodus ramosus, Agass.,	×	×	×	×	–	–	–	–
,, cinctus, Agass.,	×	×	×	–	–	–	×	–
,, porosus, M'Coy,	×	–	–	–	–	–	–	–
,, compressus, M'Coy,	×	–	–	–	–	–	–	–
,, elongatus, Agass.,	×	–	–	–	–	–	–	–
,, augustus, Agass.,	×	–	–	–	–	–	–	–
,, catenatus, Agass.,	×	–	–	–	–	–	–	–
,, gibbus, Agass.,	×	–	–	–	–	–	–	–
,, sculptus, Davis,	–	–	–	–	–	–	–	–
,, ornatus, Davis,	–	–	–	–	–	–	–	–
,, moniliformis, Davis,	–	–	–	–	–	–	–	–
,, Reedi, Davis,	–	–	–	×	–	–	–	–
,, tenuis, Davis,	–	–	–	–	–	–	–	–
,, subteres, Agass.,	–	×	×	–	–	–	–	–
Petrodus patelliformis, M'Coy,	–	–	–	–	×	–	×	–
Rhamphodus dispar, Davis,	×	–	–	–	–	–	–	
Lophodus lævissimus, Agass.,	×	×	×	–	–	–	×	–
,, gibberulus, Agass.,	×	×	–	–	–	–	–	–
,, mammilaris, Agass.,	×	–	×	–	–	–	×	–
,, didymus, Agass.,	×	–	×	–	–	–	×	–
,, reticulatus, Davis,	–	–	–	×	–	–	–	–
,, serratus, Davis,	–	–	–	–	–	–	–	–
,, bifurcatus, Davis,	–	–	–	–	–	–	–	–
,, lævis, Davis,	–	–	–	–	–	–	–	–
,, sinuosus, Davis,	–	–	–	–	–	–	–	–
Diclitodus scitulus, Davis,	–	–	–	×	–	–	–	–
COCHLIODONTIDÆ.								
Cochliodus contortus, Agass.,	×	×	×	×	–	×	×	–
Streblodus oblongus, Agass.,	×	–	–	–	–	–	–	–
,, Colei, Agass.,	×	–	–	–	–	–	–	–
,, Egertoni, Agass.,	Hook point.	–	–	–	–	–	–	–
Deltodus sublævis, Agass.,	×	–	–	–	–	–	–	–
,, expansus, Agass.,	–	–	–	–	–	–	–	–
,, aliformis, Agass.,	–	–	–	×	×	–	×	–
Deltoptychius acutus, Agass.,	×	×	–	×	×	–	×	–
,, gibberulus, Agass.,	×	–	–	–	–	–	–	–
Sandalodus Morrisii, Davis,	–	×	×	–	–	–	–	–
Psephodus magnus, Agass.,	×	–	–	×	×	×	×	×
Pœcilodus Jonesii, Agass.,	×	–	–	×	–	–	×	×
,, obliquus, Agass.,	×	–	–	–	–	–	×	–
,, corrugatus, Davis,	–	–	–	–	×	–	–	–
,, foveolatus, M'Coy,	–	–	–	–	×	–	–	–

TABLE—*continued.*

Name.	Armagh (Ireland).	Bristol.	Salop, Oreton, and Farlow.	York-shire.	Derby-shire.	Kendal, West-moreland.	W. Scotland.	Lowick, N.W.
Pœcilodus gibbosus, Davis,	–	–	–	–	–	–	–	–
Tomodus convexus, Agass.,	–	×	–	–	–	–	×	–
Xystrodus striatus, Agass.,	×	–	–	–	–	–	×	×
,, angustus, Agass.,	×	–	–	–	–	–	×	–
,, Egertoni, Davis,	–	–	–	–	–	–	–	–
,, pulchellus, Davis,	–	–	–	–	–	–	–	–
Helodus crassus, Davis,	×	–	–	–	–	–	–	–
,, tenuis, Davis,	×	–	–	–	–	–	–	–
,, clavatus, Davis,	×	–	–	–	–	–	–	–
,, acutus, Davis,	×	–	–	–	–	–	–	–
,, Richmondiensis, Davis,	×	–	–	–	–	–	–	–
,, triangularis, Davis,	×	–	–	–	–	–	–	–
,, expansus, Davis,	×	–	–	–	–	–	–	–
,, rudis, M'Coy,	×	–	–	–	–	–	–	–
Pleurodus Woodi, Davis,	–	–	–	–	–	–	–	–
PSAMMODONTIDÆ.								
Psammodus rugosus, Agass.,	×	×	–	×	–	×	×	×
COPODONTIDÆ.								
Copodus cornutus, Agass.,	×	–	–	×	–	–	–	–
,, furcatus, Agass.,	×	–	–	–	–	–	–	–
,, spatulatus, Agass.,	×	–	–	–	–	–	–	–
,, minimus, Davis,	×	–	–	–	–	–	–	–
Labodus prototypus, Agass.,	×	–	–	–	–	–	–	–
,, planus, Agass.,	×	–	–	–	–	–	–	–
Mesogomphus lingua, Agass.,	×	–	–	–	–	–	–	–
Pleuragomphus auriculatus, Agass.,	×	–	–	–	–	–	–	–
Rhymodus transversus, Agass.,	×	–	–	–	–	–	–	–
,, oblongus, Davis,	×	–	–	–	–	–	–	–
Characodus angulatus, Agass.,	×	–	–	–	–	–	–	–
,, cuneatus, Agass.,	×	–	–	–	–	–	–	–
Pinacodus gonoplax, Agass.,	×	–	–	–	–	–	–	–
,, gelasimus, Agass.,	×	–	–	–	–	–	–	–
[illegible]ylius Woodi, Agass.,	–	–	–	×	–	–	–	–
[illegible]lax batoides, Agass.,	×	–	–	–	–	–	–	–
Mylacodus quadratus, Agass.,	×	–	–	–	–	–	–	–
,, sesamini, Agass.,	×	–	–	–	–	–	–	–
Homalodus trapeziformis, Davis,	×	–	–	–	–	–	–	–
,, quadratus, Davis,	×	–	–	–	–	–	–	–
PETALODONTIDÆ.								
Petalodus Hastingsiæ, Owen,	×	–	–	–	–	–	×	×
,, acuminatus, Agass.,	–	–	–	×	×	–	–	×
,, rectus, Agass.,	×	–	–	–	–	–	×	×
,, grandis, Davis,	×	–	–	–	–	–	–	–
,, recurvus, Davis,	×	–	–	–	–	–	–	–
,, inequilateralis, Davis,	×	–	–	–	–	–	–	–
Petalopsodus tripartitis, Davis,	–	–	–	×	–	–	–	–
Polyrhizodus radicans, Agass.,	×	–	–	–	–	–	×	×
,, Colei, Davis,	×	–	–	–	–	–	–	–
,, elongatus, Davis,	×	–	–	–	–	–	–	–
,, sinuosus, Davis,	×	–	–	–	–	–	–	–
,, attenuatus, Davis,	×	–	–	–	–	–	–	–
,, constrictus, Davis,	×	–	–	–	–	–	–	–
Chomatodus linearis, Agass.,	×	×	×	–	–	–	×	–
,, acutus, Agass.,	–	–	–	–	–	–	–	–
Glossodus marginatus, M'Coy,	×	–	–	–	–	–	×	–
Ctenopetalus serratus, Agass.,	×	–	×	–	–	–	×	–
,, crenatus, Davis,	–	–	–	×	–	–	–	–
Harpacodus dentatus, Agass.,	×	–	–	–	–	–	×	×
,, clavatus, Davis,	×	–	–	–	–	–	–	–
Petalorhynchus psittacinus, Agass.,	×	–	–	–	–	–	×	–
INCERTA SEDIS.								
Pristodus falcatus, Agass.,	–	–	–	×	×	–	–	–

TABLE—*continued.*

Name.	Armagh (Ireland).	Bristol.	Salop, Oreton, and Farlow.	York-shire.	Derby-shire.	Kendal, West-moreland.	W. Scotland.	Lowick, N.W.	Tort-worth.
GANOIDEI.									
Cheirodus pes-ranæ, M'Coy, . .	–	–	–	×	×	–	–	–	–
Colonodus longidens, M'Coy, . .	×	–	–	–	–	–	–	–	–
Cœlacanthus sp? Agass., . . .	×	–	–	–	–	–	–	–	–
Oracanthus sp? Agass., . . .	×	×	–	–	–	–	–	–	–
Stichacanthus tortworthensis, Davis, .	–	–	–	–	–	–	–	–	×
Phoderacanthus grandis, Davis, . .	–	×	–	–	–	–	–	–	–

The preceding Table of Localities has been compiled principally from the following sources :—

Ireland, principally Armagh, &c.—The Collection of Lord Enniskillen, and M. Agassiz's "Poissons Fossiles."

Bristol—Agassiz "Poissons Fossiles," and the Bristol Museum Collection.

Oreton and Farlow—Messrs. Morris and Roberts, "Quarterly Journal, Geological Society," Vol. XVIII., p. 99, *et seq.*

Yorkshire, principally Leyburn, Richmond, Settle and Kettlewell—Collections of Dr. Reed at the York Museum, and William Horne, Esq., of Leyburn.

Derbyshire—Prof. M'Coy's, "British Palæozoic Fossils," and Woodwardian Museum, Cambridge.

Westmoreland—Collection at the Museum of the Philosophical and Literary Society, Leeds.

Western Scotland—Messrs. Young and Armstrong's lists in the "Trans. of the Geological Society, Glasgow," Vol. III., supt. p. 68, *et seq.*, and Messrs. Armstrong, Young and Robertson's "Catalogue of the Western Scottish Fossils." Glasgow, 1876.

Northumberland, Lowick, &c.,—Collection at the Woodwardian Museum, and Prof. M'Coy's "British Palæozoic Fossils."

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Probably posterior dorsal spine.

Limestone, Bristol, ... *Ex. coll.*, Bristol Museum.

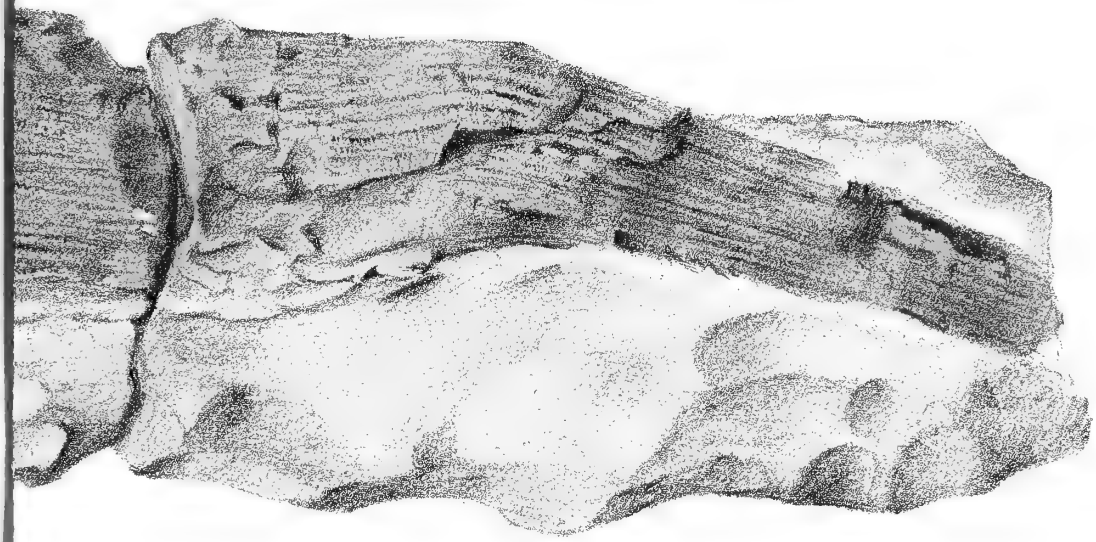
Fig. 2. Ctenacanthus major, Agass.,	. . . .	334

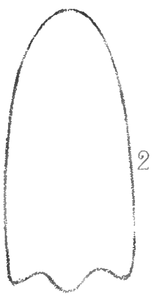
Probably anterior dorsal spine.

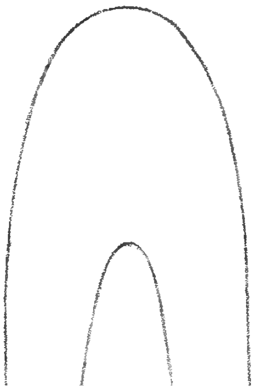
„ 2 *b*. Section across the latter near the basal extremity.
„ 2 *c*. „ „ near the point.
„ 2 *d*. Enlarged representation of surface markings.

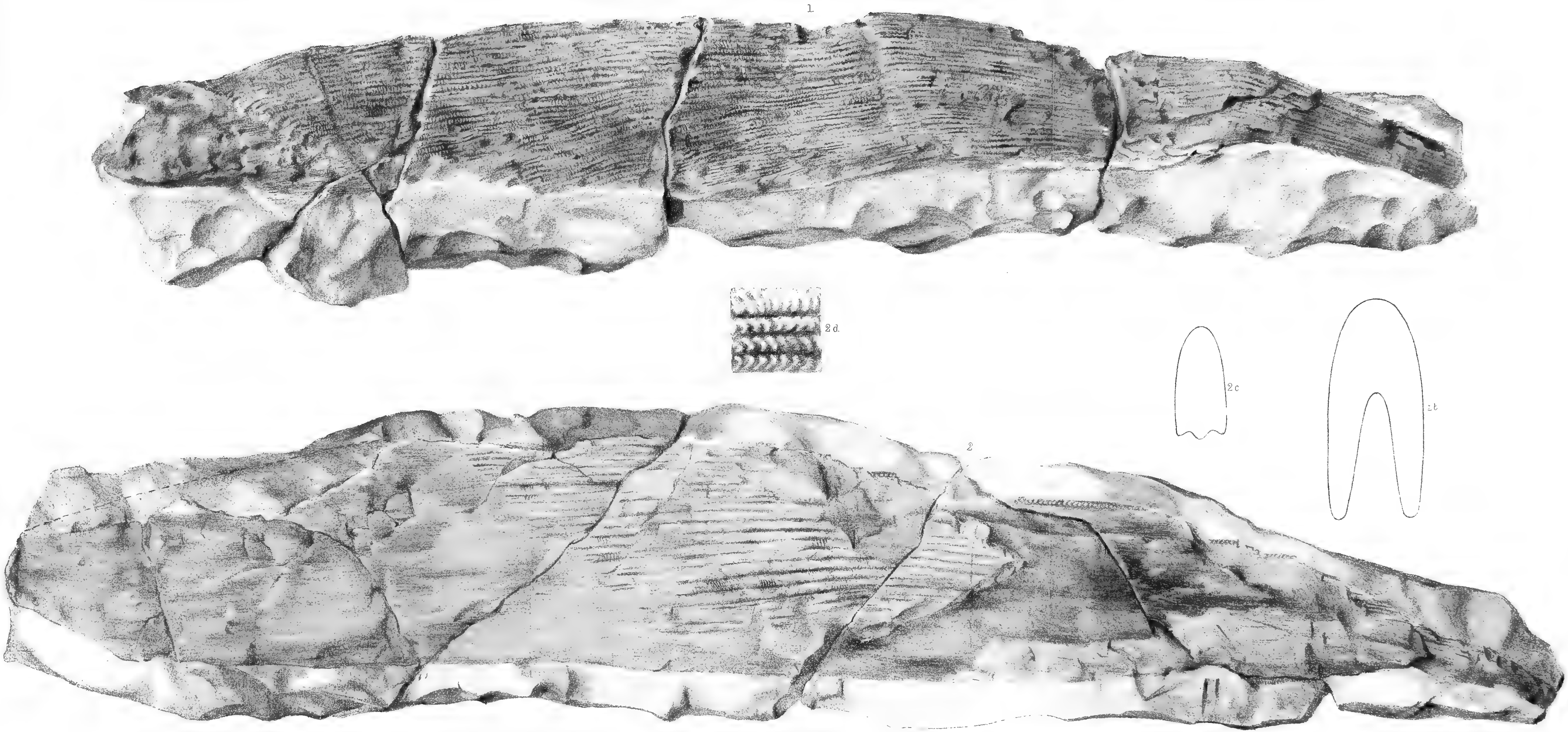
Limestone, Armagh, . . . *Ex. coll.* Enniskillen Collection.

Natural size.




2 c.


2 b



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A large but imperfect specimen.		
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Limestone, Bristol, . .	*Ex. coll.* Enniskillen Collection.	
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Limestone, Bristol, ...	*Ex. coll.* Bristol Museum.	
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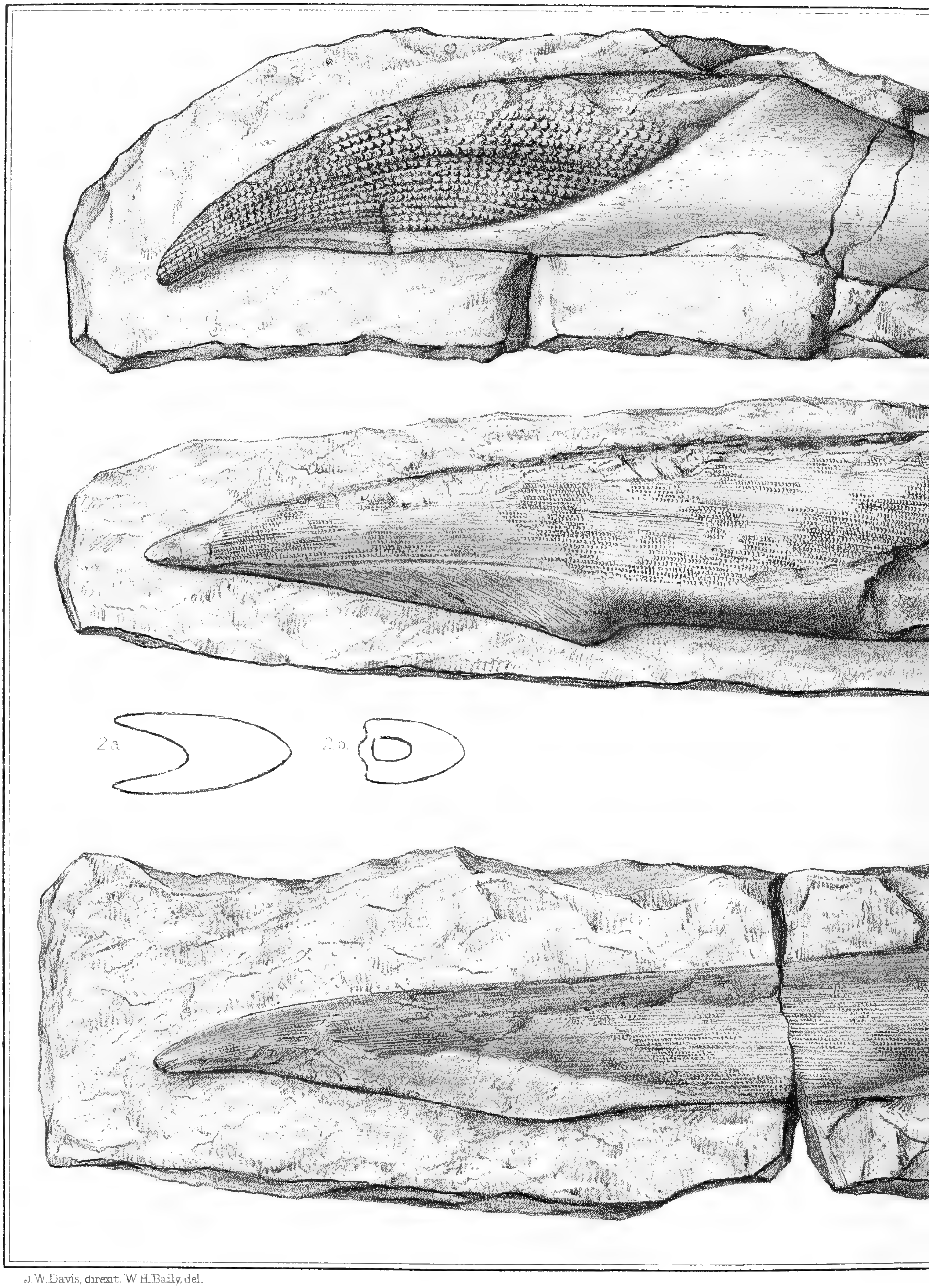
Limestone, Armagh, . . .	*Ex. coll.* Enniskillen Collection.	

Natural size.



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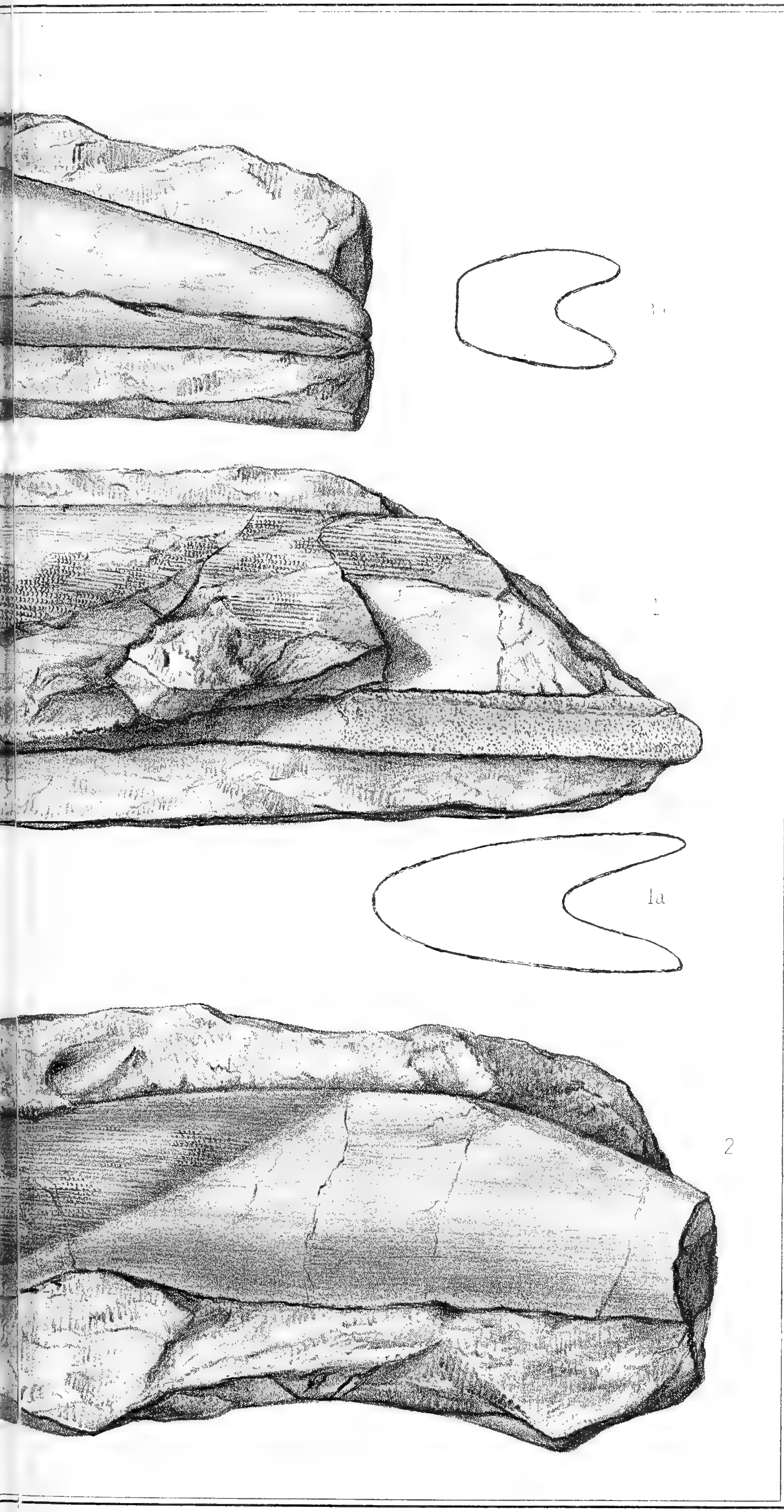

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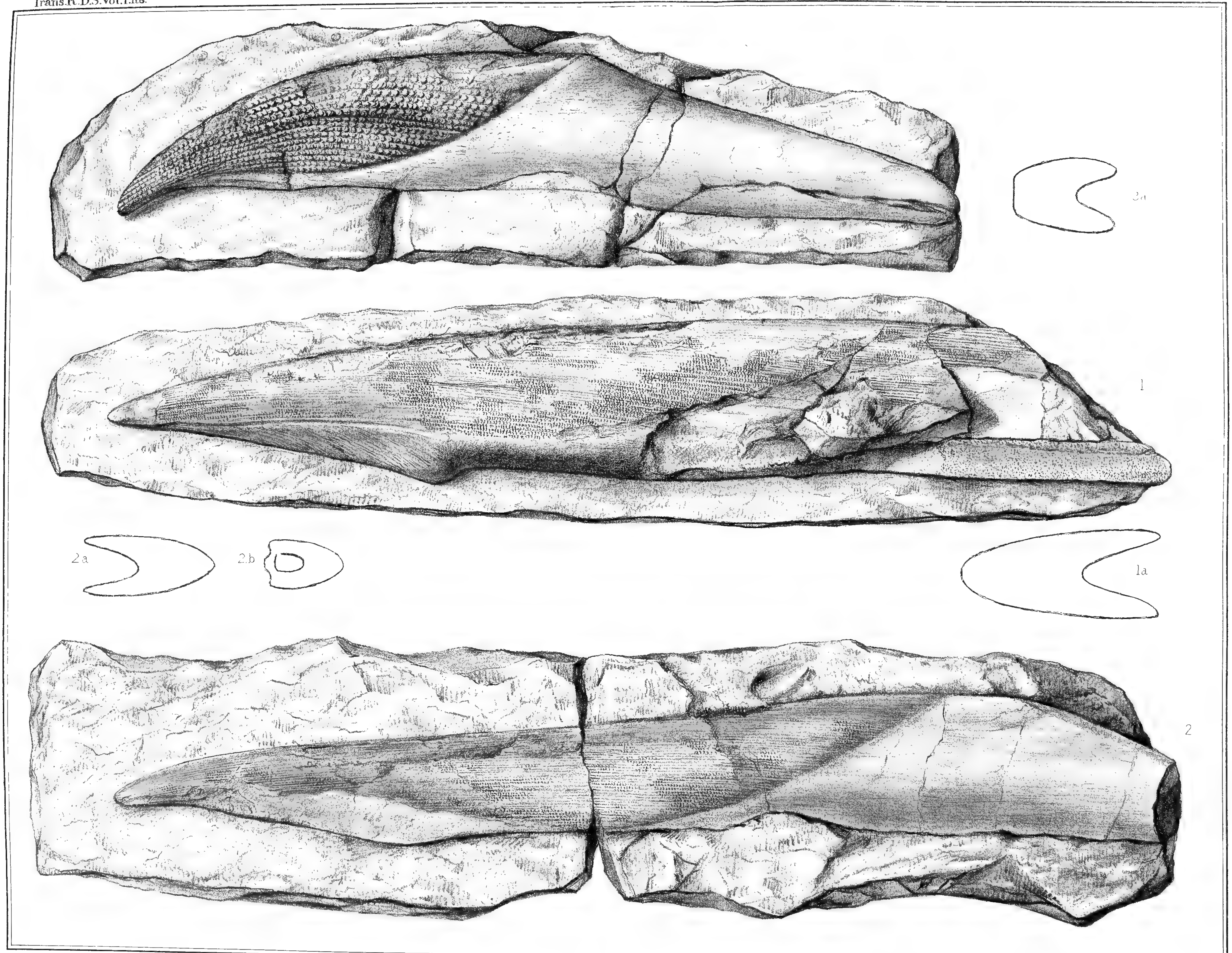

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Limestone, Armagh, . .	*Ex coll.* Enniskillen Collection.	
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Limestone, Oreton in Salop, Bristol,	*Ex coll.* Enniskillen Collection.	
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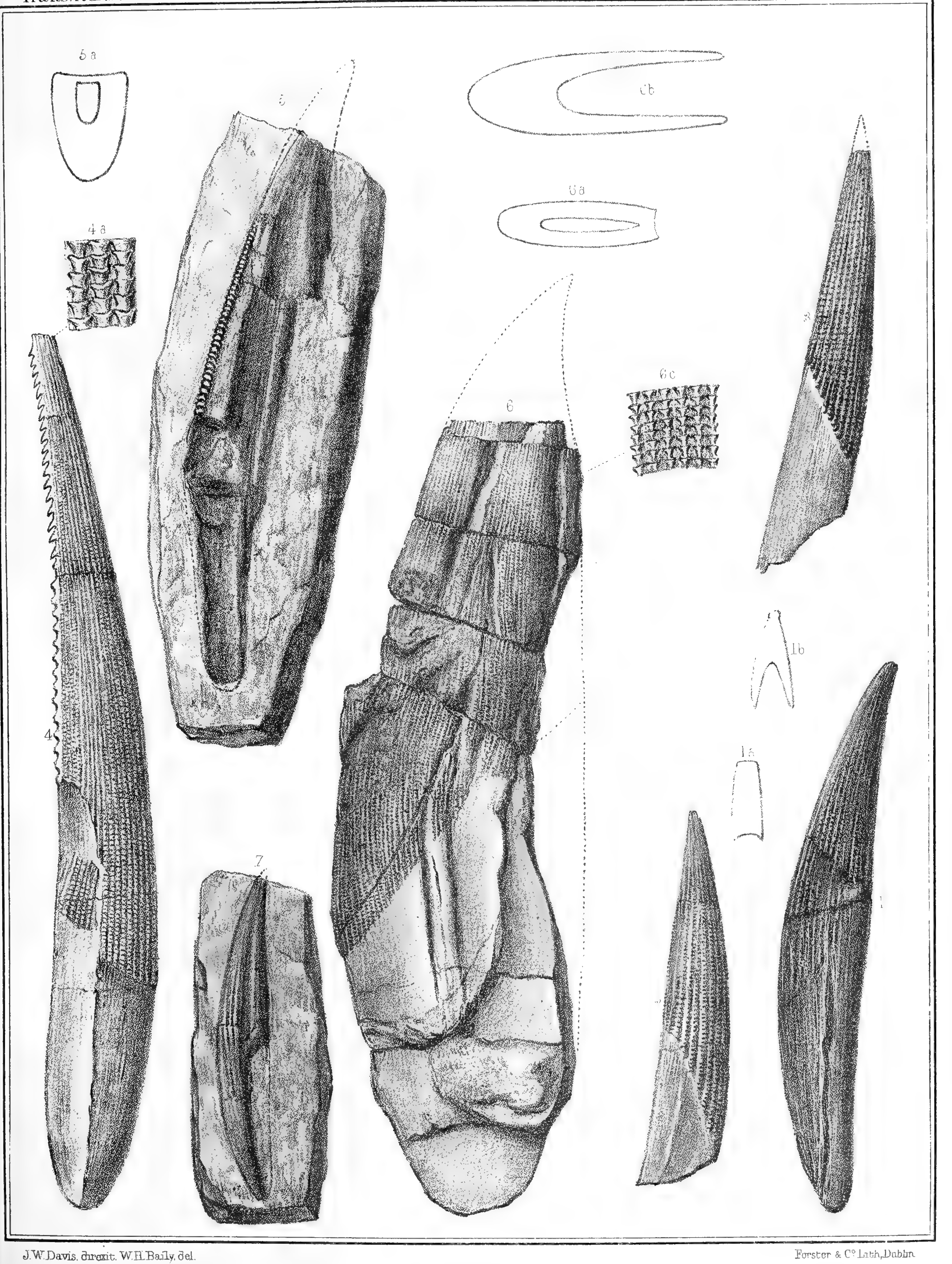
Limestone, Armagh, .	*Ex coll.* Enniskillen Collection.	



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Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

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Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

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Limestone, Armagh, . *Ex coll.* Geological Society's Museum.

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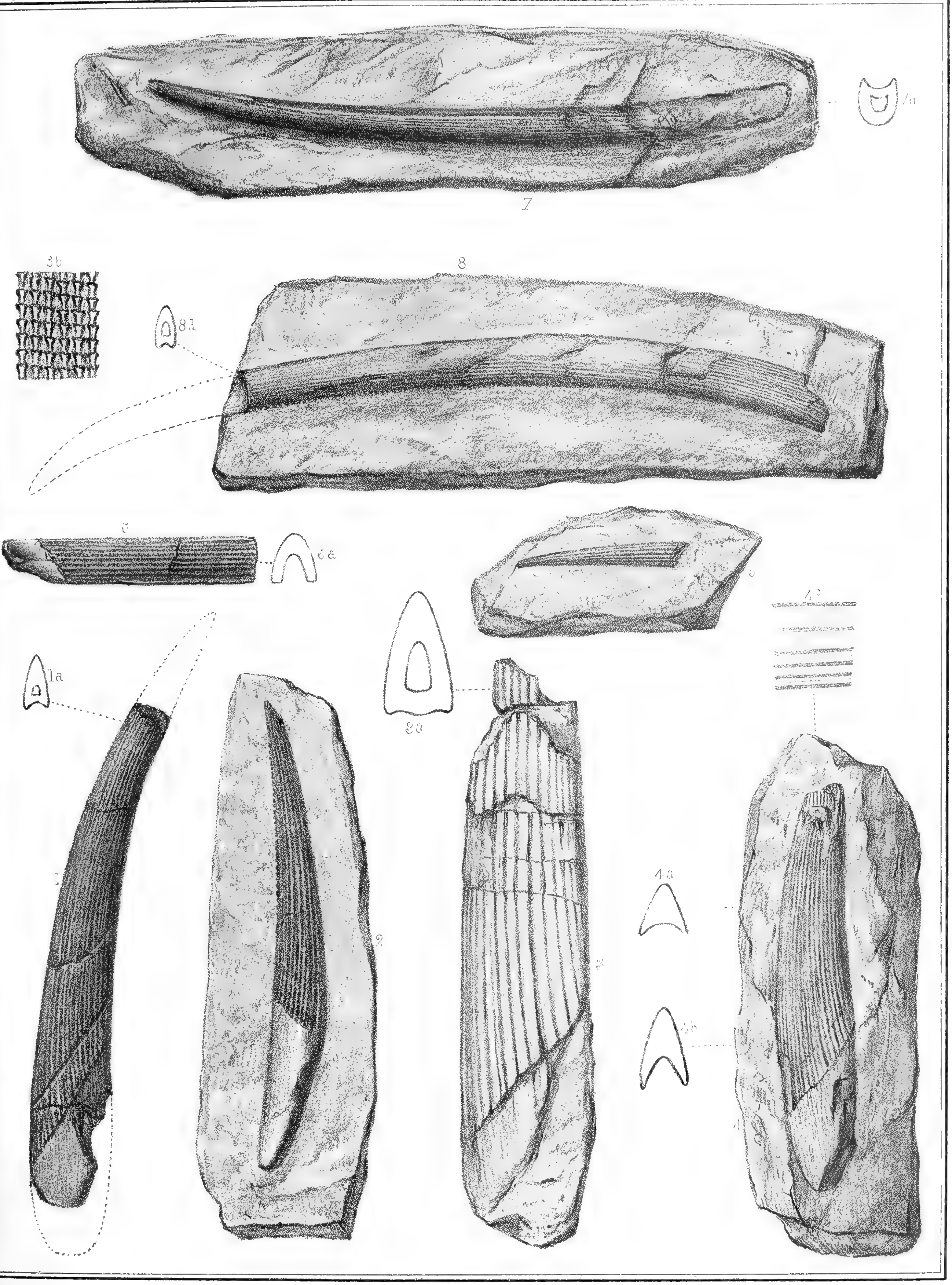
„ 8 *b.* Part of surface enlarged.

Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.



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Carboniferous Limestone, Armagh, . . *Ex coll.* Earl of Enniskillen.

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Carboniferous Limestone, Lowick, Northumberland.
Ex coll. Woodwardian Museum, Cambridge.

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Carboniferous Limestone, Armagh, *Ex coll.* Woodwardian Museum, Camb.

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Limestone, Armagh, . . . *Ex coll.* Earl of Enniskillen.

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Limestone, Armagh, . . . *Ex coll.* Enniskillen Collection.

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Limestone, Armagh, . . . *Ex coll.* Enniskillen Collection.

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Limestone, Armagh, . . . *Ex coll.* Enniskillen Collection.

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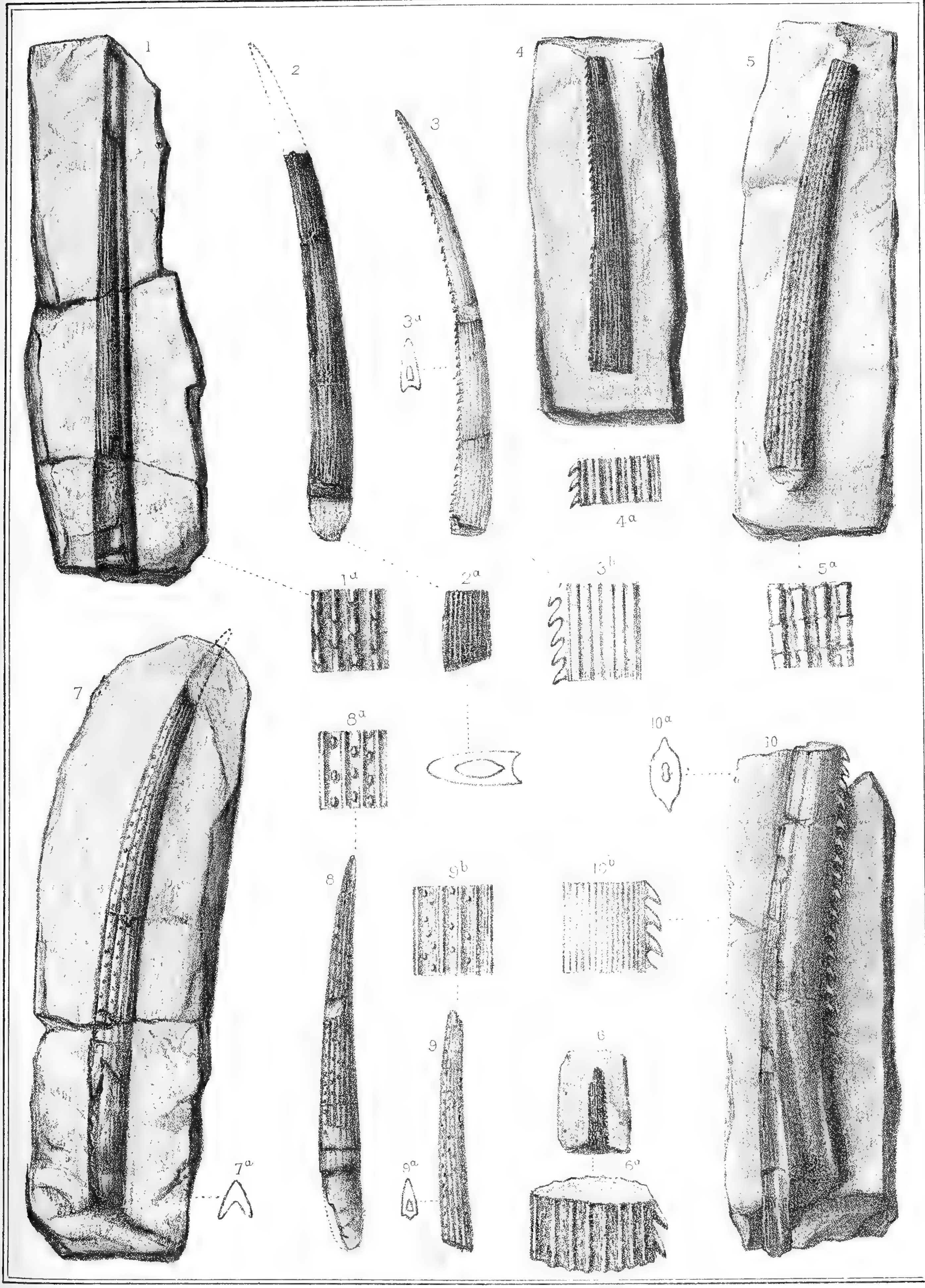
Limestone, Armagh, . . . *Ex coll.* Enniskillen Collection.



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,, 1 *a*. Transverse section of the anterior branch of the spine.		
,, 1 *b*. Transverse section of the posterior branch of the spine.		
Carboniferous Limestone, Armagh, .	*Ex. coll.* Enniskillen Collection.	
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Carboniferous Limestone, Armagh, .	*Ex. coll.* Enniskillen Collection.	
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,, 3 *a*. The same magnified.		
Carboniferous Limestone, Armagh, .	*Ex. coll.* Enniskillen Collection.	
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Carboniferous Limestone, Armagh, .	*Ex. coll.* Enniskillen Collection.	
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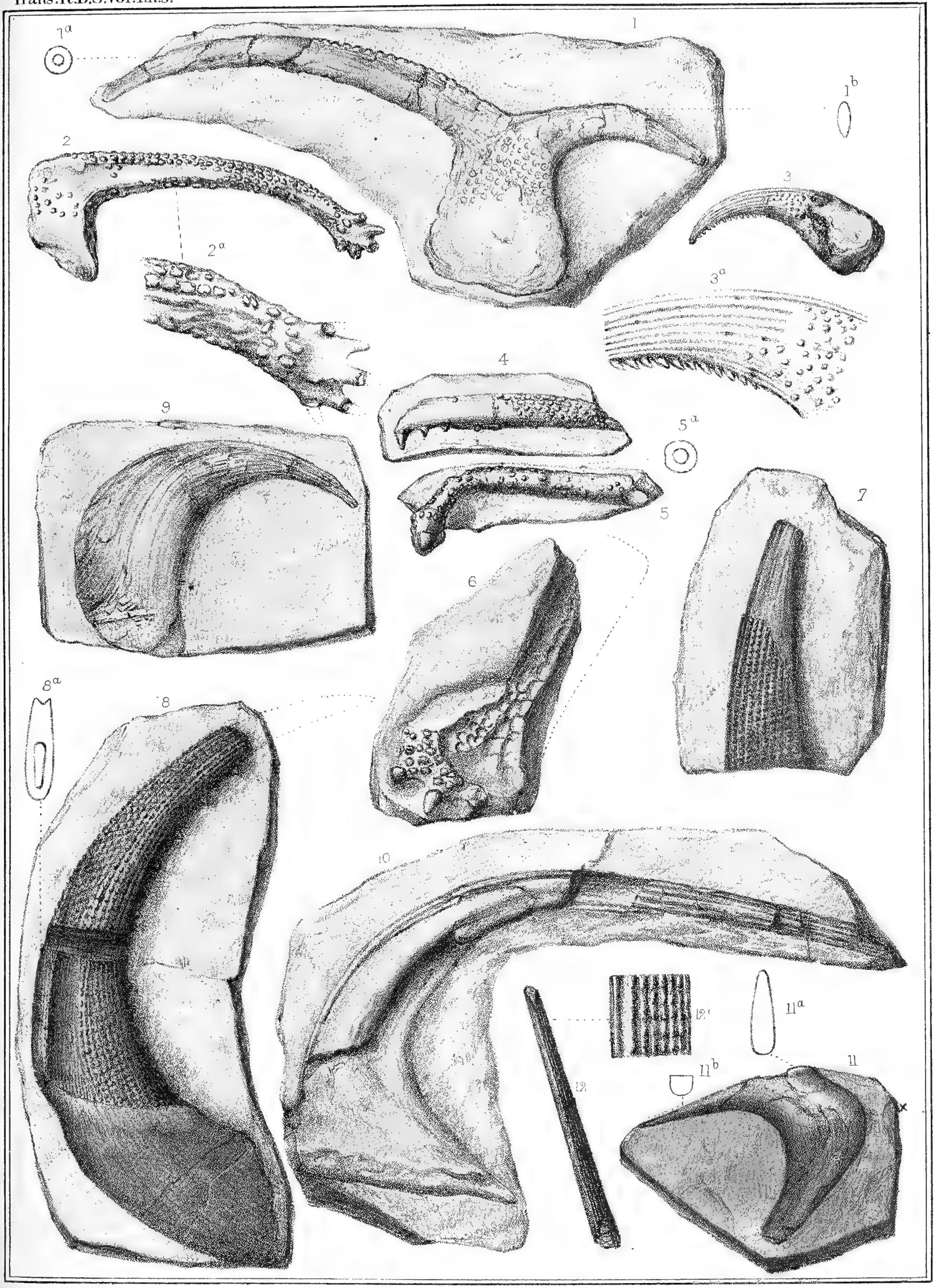
Carboniferous Limestone, Armagh,	*Ex. coll.* Geological Society of London.	



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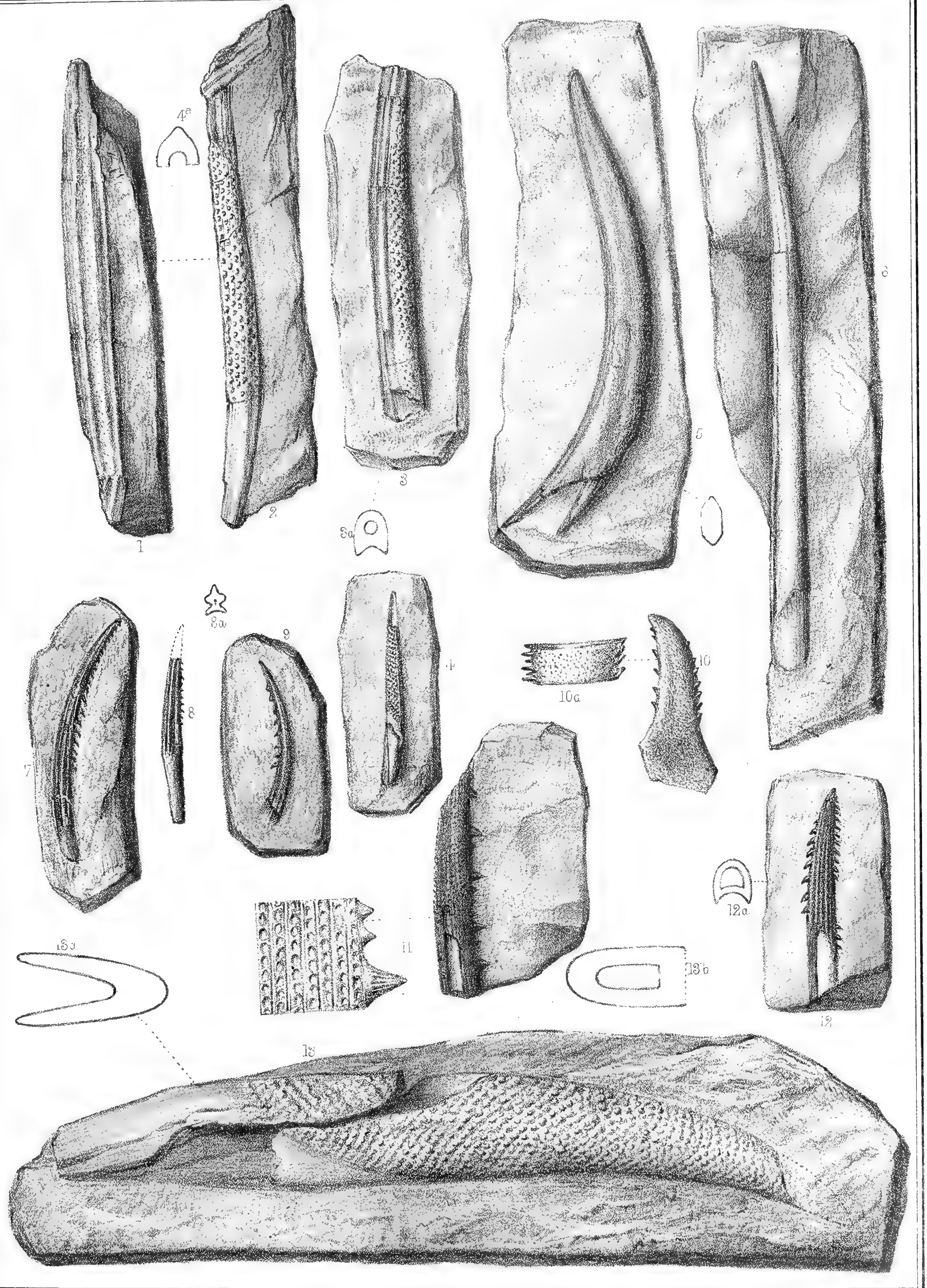

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Carboniferous Limestone, Armagh,	*Ex coll.* Enniskillen Collection.	
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Limestone, Bristol,	*Ex coll.* Bristol Museum	
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Mountain Limestone, Armagh,	*Ex coll.* Enniskillen Collection.	
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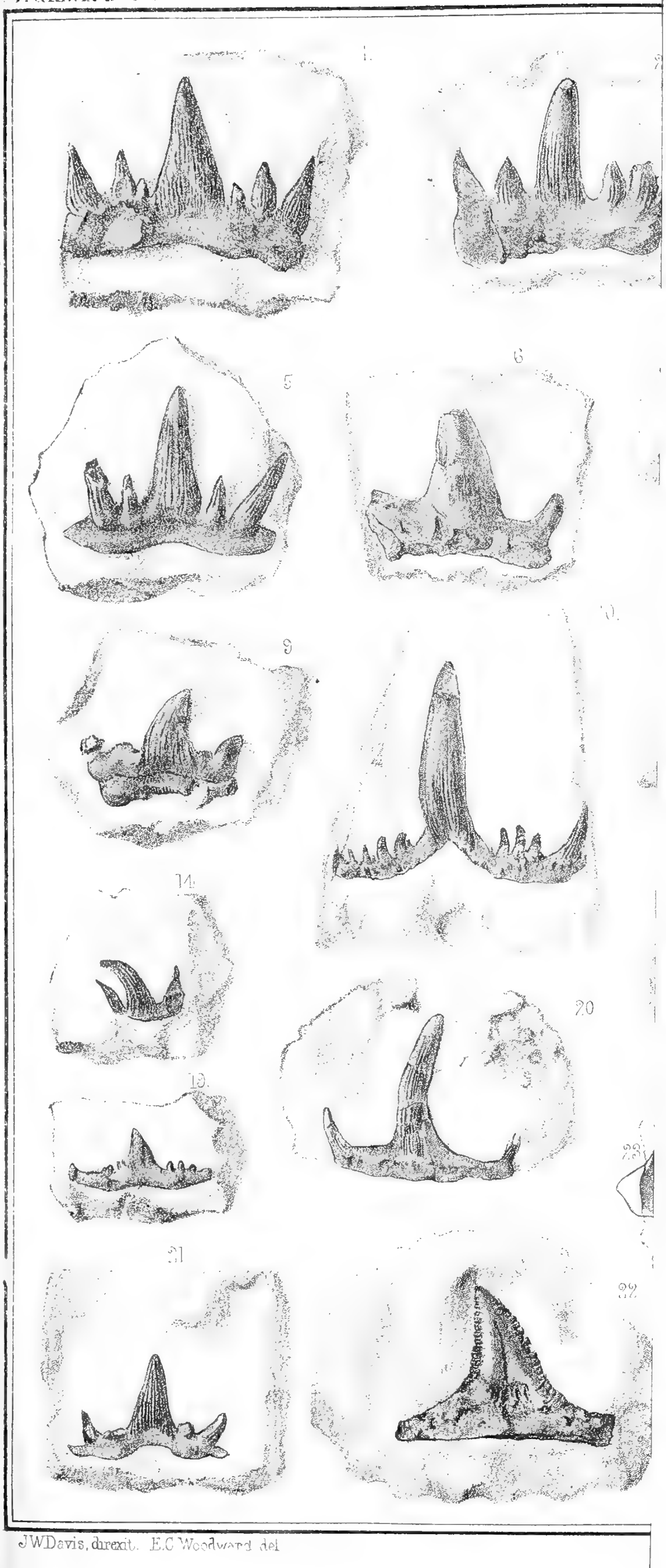

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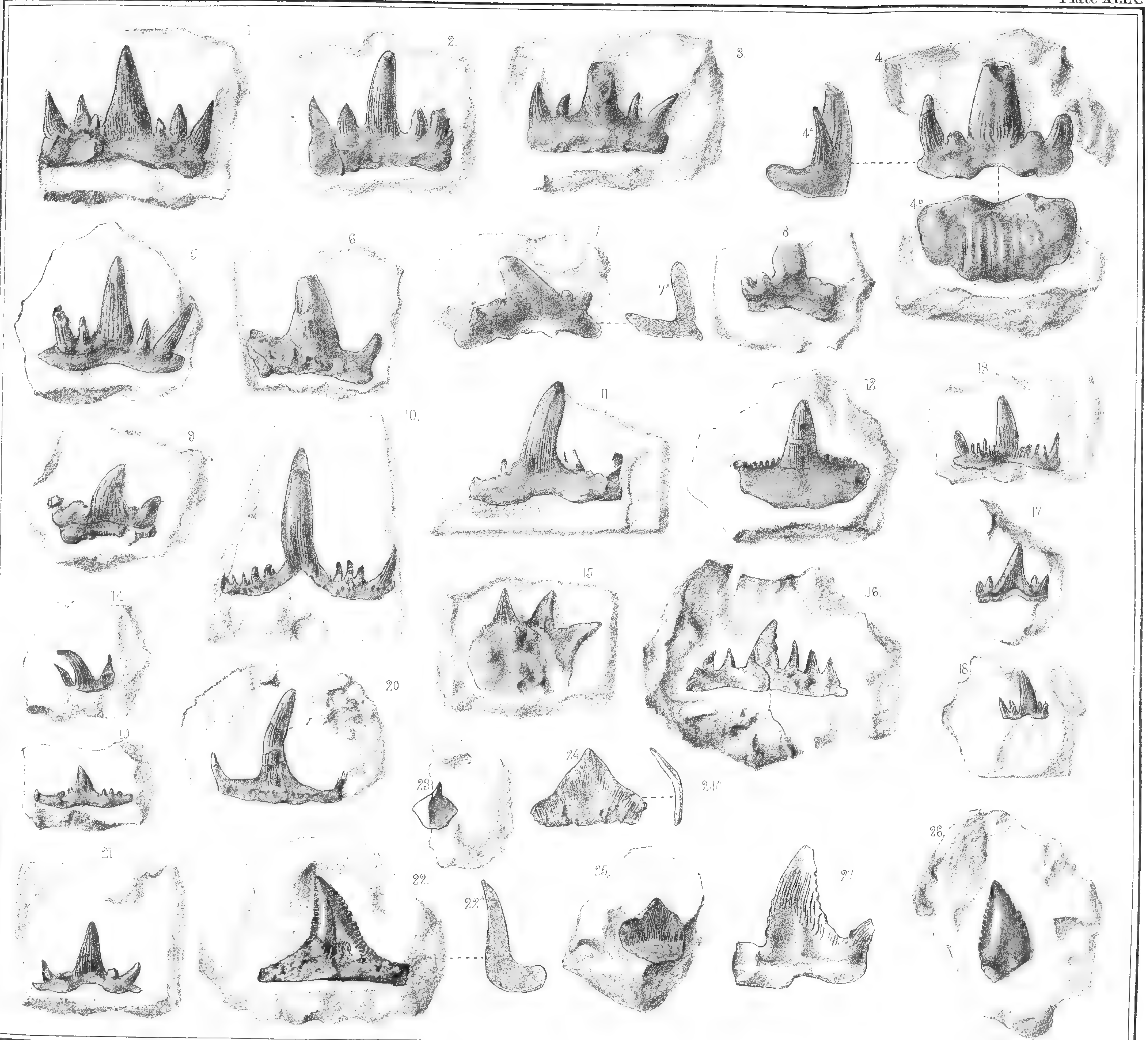

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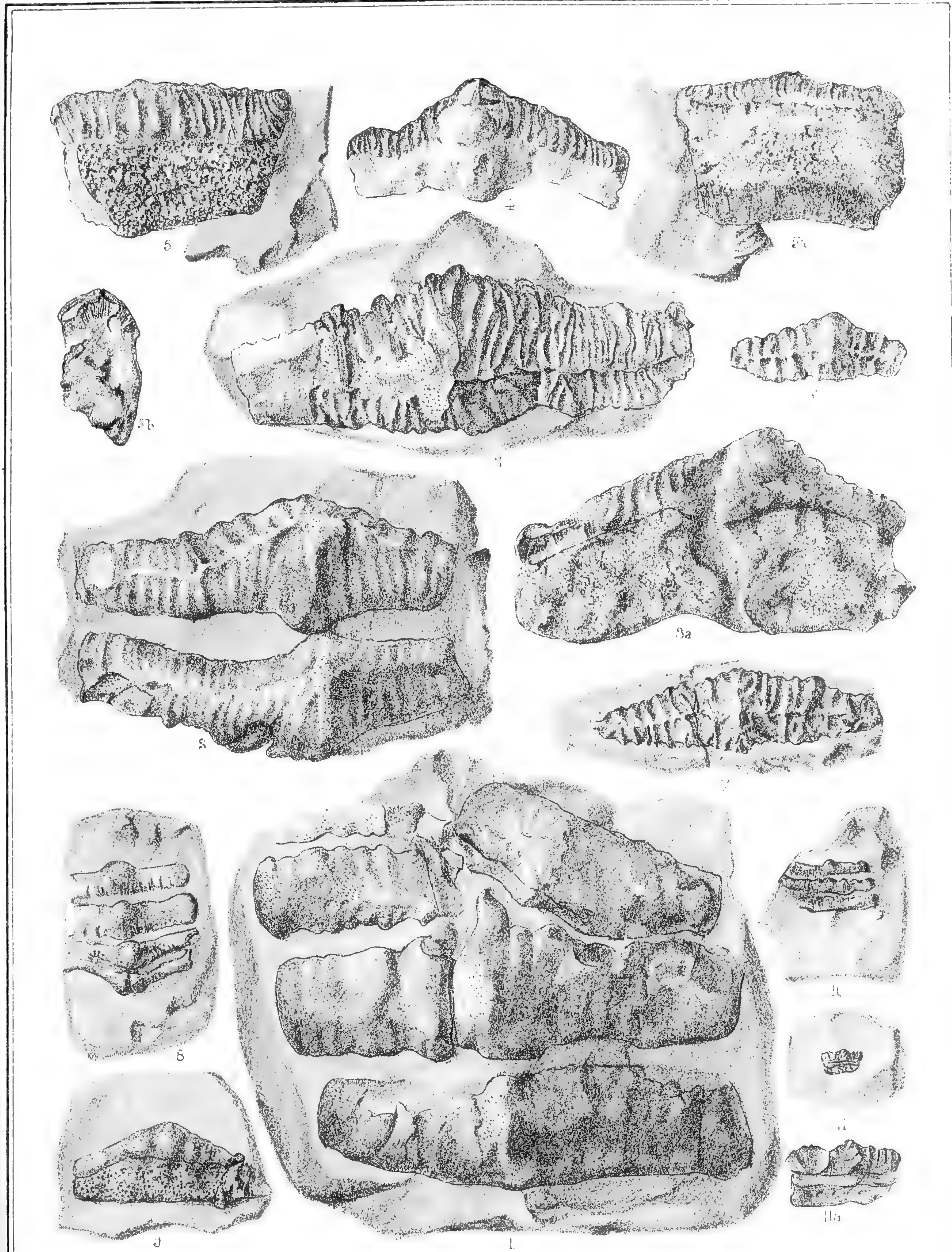

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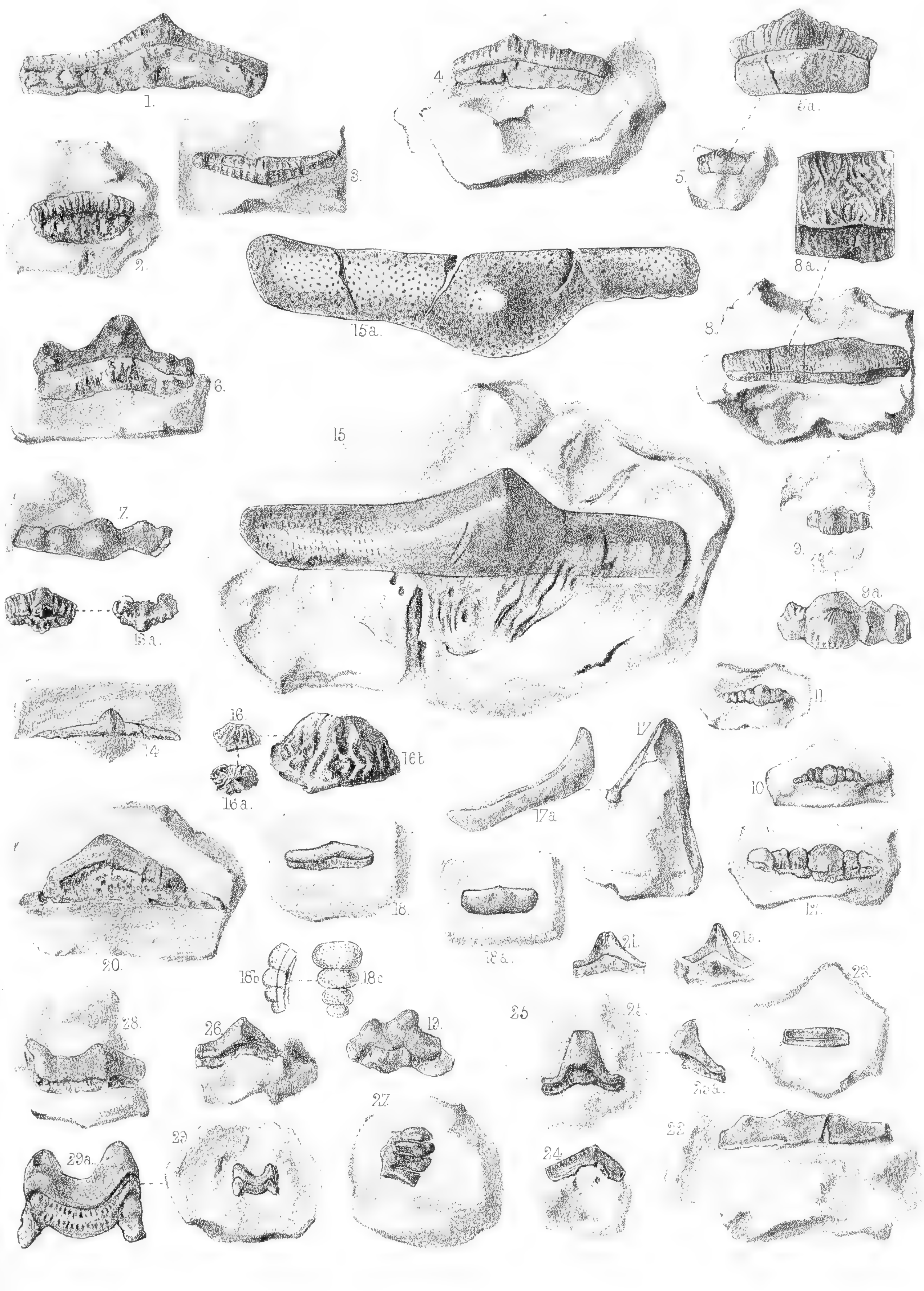

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Mountain Limestone, Clifton, Bristol, . *Ex coll.* Earl of Enniskillen.	
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Mountain Limestone, Bristol. . *Ex coll.* Enniskillen Collection.	
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Mountain Limestone, Bristol, . *Ex coll.* Enniskillen Collection.	
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Mt. Limestone, Clifton, Bristol, *Ex. coll.* Woodwardian Museum, Cambridge.	
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Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.	
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Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.	

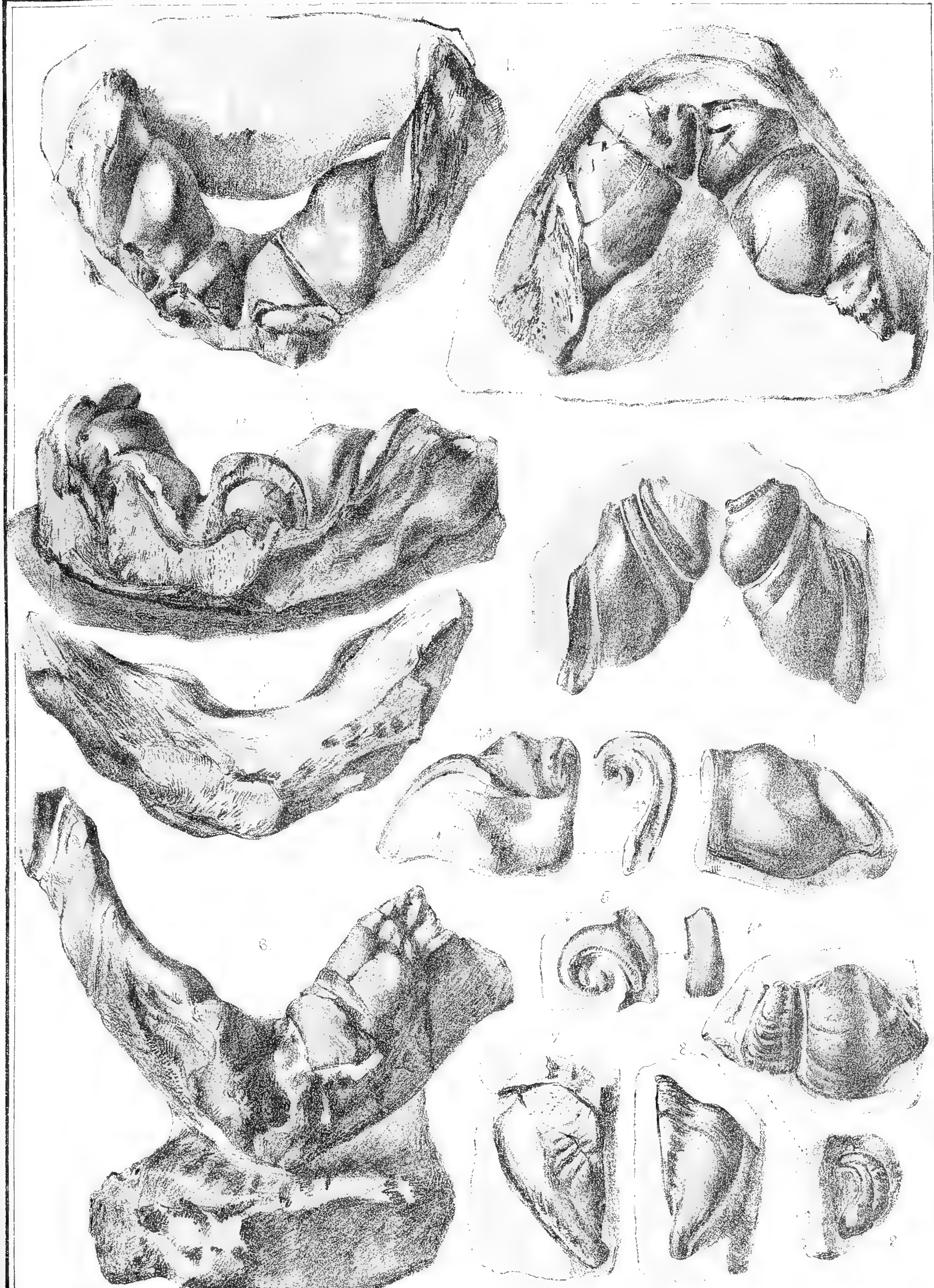

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FIG. 1. STREBLODUS OBLONGUS, Agass., ... 424
Teeth of the right and left ramus of the jaw with a connecting palatal base.

FIG. 2. STREBLODUS OBLONGUS, Agass., ... 424
Upper surface of posterior tooth.

FIG. 3. STREBLODUS OBLONGUS, Agass., ... 424
Under side of posterior tooth.

FIG. 4. STREBLODUS OBLONGUS, Agass., ... 424
Tooth attached to a wide expansion of the bony jaws or palate.
All from Mountain Limestone, Armagh, *Ex coll.* Enniskillen Collection.

FIGS. 5, 6. STREBLODUS COLEI, Agass., ... 425
Posterior teeth, right and left respectively.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 7, 8. STREBLODUS EGERTONI, Agass., ... 426
Mt. Limestone, Hook Point, Co. Wexford, *Ex coll.* Enniskillen Collection.

FIGS. 9, 10. DELTODUS EXPANSUS, Davis, ... 431
Right and left teeth of the upper jaw.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 11. DELTODUS EXPANSUS, Davis, ... 431
Tooth of the lower jaw.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 12. DELTODUS ALIFORMIS, M'Coy, ... 431
Upper Limestone, Derbyshire, *Ex. coll.* Woodwardian Museum, Cambridge.

FIGS. 13, 14. DELTOPTYCHIUS ACUTUS, Agass., ... 433
Right and left teeth of the lower jaw.

„ 14 *a.* Posterior surface of figure 14, enrolled over the jaw.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 15. DELTOPTYCHIUS ACUTUS, Agass., ... 433
A large example of tooth from the upper jaw.

FIG. 16. DELTOPTYCHIUS ACUTUS, Agass., ... 433
Under side of figure 15.

FIG. 17. DELTOPTYCHIUS ACUTUS, Agass., ... 433
A smaller example from the opposite ramus of a jaw to the one represented in figure 15.
Carboniferous Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 18, 19. DELTOPTYCHIUS GIBBERULUS, AGASS., ... 435
Teeth of the lower and upper jaws respectively.
Carboniferous Limestone, Bristol and Hook point, Co. Wexford.
Ex coll. Enniskillen Collection.

FIGS. 20, 21, 23. PŒCILODUS JONESII, Agass., ... 442
Posterior teeth.
Carboniferous Limestone, Armagh, *Ex coll.* Enniskillen Collection.

FIG. 22. PŒCILODUS JONESII, ... 442
Anterior tooth.
Carboniferous Limestone, Armagh, *Ex coll.* Enniskillen Collection.

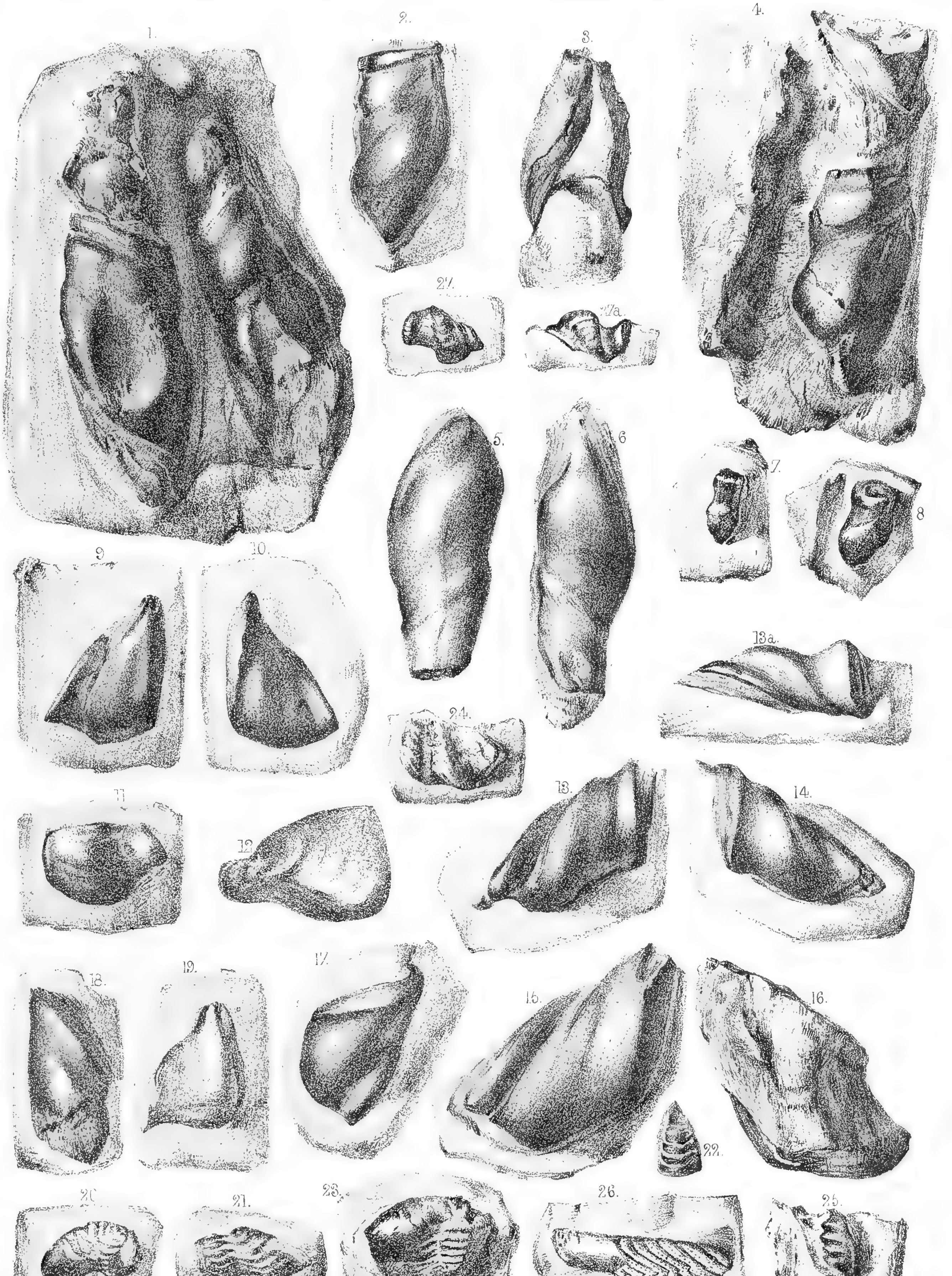
FIG. 24. PŒCILODUS OBLIQUUS, Agass., ... 444
Posterior tooth.
Carboniferous Limestone, Armagh, *Ex coll.* Enniskillen Collection.

FIG. 25. PŒCILODUS CORRUGATUS, Davis, ... 443
Carboniferous Limestone, Wensleydale, *Ex coll.* William Horne, Esq.

FIG. 26. PŒCILODUS FOVEOLATUS, M'Coy, ... 445
Carb. Limestone, Derbyshire, *Ex. coll.* Woodwardian Museum, Cambridge.

FIG. 27. PŒCILODUS GIBBOSUS, Davis, ... 445

„ 27*a.* Posterior surface, showing the enrolment over the jaw.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.



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DESCRIPTION OF PLATE LIV.

PLATE LIV.

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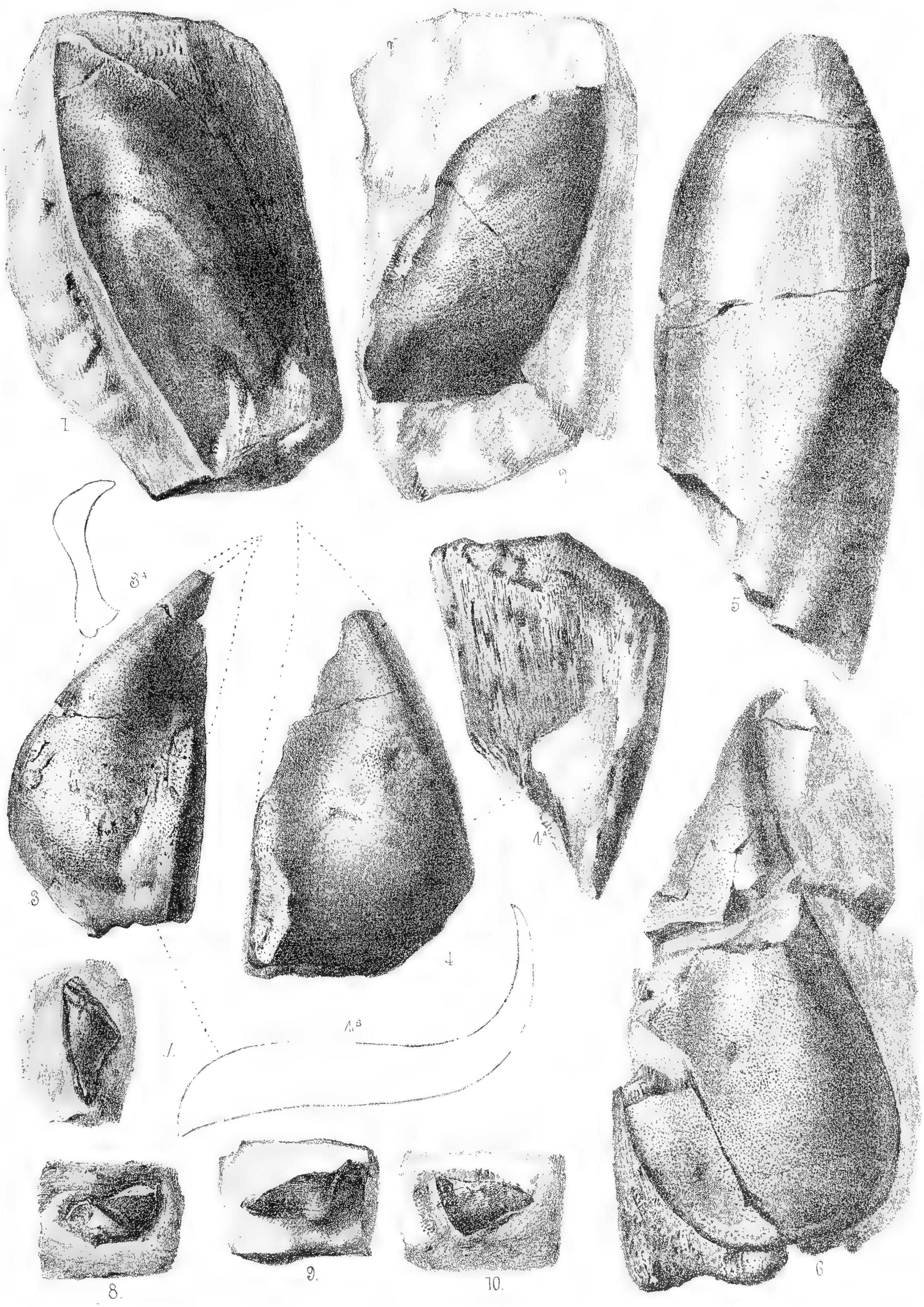
FIGS. 1, 2. SANDALODUS MORRISII, Davis, ... 437
Teeth of left and right rami of the lower jaw.
Mountain Limestone, Bristol, . . *Ex coll.* Bristol Museum.

FIGS. 3, 4. SANDALODUS MORRISII, Davis, ... 437
Teeth of left and right rami of the upper jaw.
,, 3 *a.* Transverse section of figure 3.
,, 3 *b.* Longitudinal section of figure 3.
,, 4 *a.* Under surface of figure 4.
Mountain Limestone, Bristol, . *Ex coll.* Dr. Grenfell, Bristol.

FIGS. 5, 6. SANDALODUS MORRISII, Davis, ... 437
Large examples of teeth of lower and upper jaws.
Mountain Limestone, Oreton, Salop, *Ex coll.* Enniskillen Collection.

FIGS. 7–10. XYSTRODUS STRIATUS, Agass., ... 448
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.



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DESCRIPTION OF PLATE LVII.

PLATE LVII.

FIG. 1. A group of three or four teeth disturbed and somewhat fragmentary.

Mountain Limestone, Bristol, . . *Ex. coll.* Bristol Museum.

FIG. 2. A thick specimen of lateral row of teeth.

FIG. 3. Triangular tooth probably occupying the anterior extremity of line of lateral teeth (see woodcut on page 462).

,, 3 *a.* Posterior extremity of same in section.

FIGS. 4, 5. Examples of ordinary form, much worn.

,, 5 *a.* Lateral elevation of figure 5, base and crown very thin.

FIG. 6. A large example peculiarly long in proportion to the breadth.

FIG. 7. Upper surface of a lateral specimen.

,, 7 *a.* Under surface of the same tooth.

Specimens represented by figures 2–7, from Mountain Limestone of Armagh,

Ex coll. Enniskillen Collection.

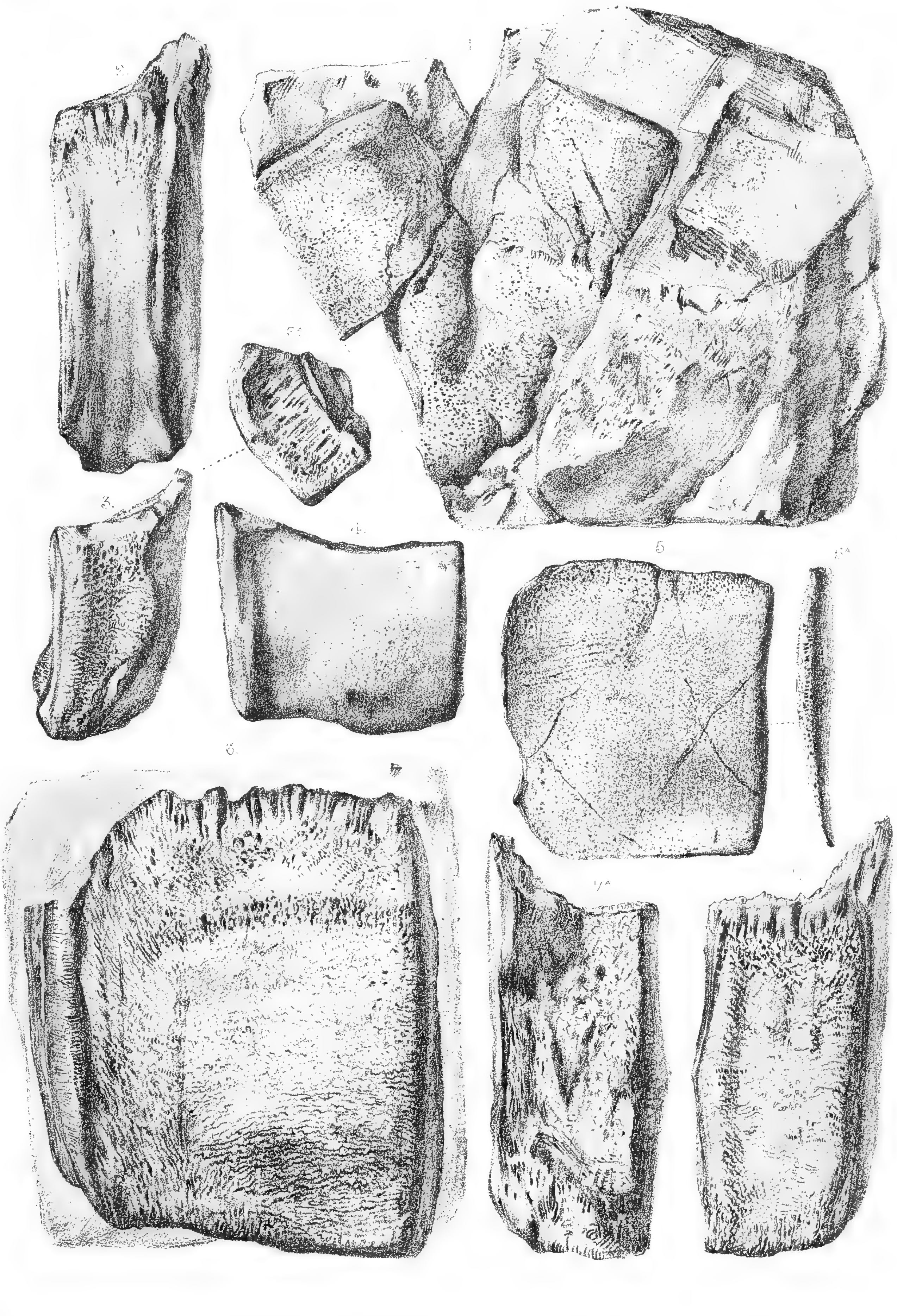

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PLATE LVIII.

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FIGS. 1–5. COPODUS CORNUTUS, Agass. 464
,, 1. Upper surface. 1 *a*. Under surface. 1 *b*. Lateral surface.
,, 3, 4. Small posterior teeth (formerly C. lunulatus, Agass.)
,, 4 *a*. Posterior surface of figure 4, showing relative proportions of crown and base.
FIGS. 2, 5. The large and small forms attached in natural position.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 6. COPODUS FURCATUS, Agass., ... 466
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 7. COPODUS SPATULATUS, Agass., ... 467
With small posterior tooth attached.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 8. COPODUS MINIMUS, Davis, ... 467
Carb. Limestone, Richmond, Yorkshire, . *Ex coll.* Enniskillen Collection.

FIGS. 9–11. LABODUS PROTOTYPUS, Agass., ... 468
,, 9. Upper surface. Fig. 10. Under surface of base.
,, 11. ,, ,, Fig. 11 *a*. ,, ,, of same.
,, 11 *b*. Posterior elevation, showing relative extent of base and crown.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIGS. 12–14. LABODUS PLANUS, Agass., ... 470
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 15. PLEUROGOMPHUS AURICULATUS, Agass., ... 472
Upper surface. Fig. 15 *a*. Under surface. Fig. 15 *b*. Anterior elevation.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 16. MESOGOMPHUS LINGUA, Agass., ... 471
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 17. RHYMODUS TRANSVERSUS, Agass., ... 473
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 18. RHYMODUS OBLONGUS, Davis, ... 473
,, 18 *a*. Under surface of same specimen.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIGS. 19, 20. CHARACODUS ANGULATUS, Agass., ... 475
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 21. CHARACODUS CUNEATUS, Agass., ... 475
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 22. PINACODUS GONOPLAX, Agass., ... 477
Pair of teeth attached in natural position.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 23. PINACODUS GELASIMUS, Agass., ... 477
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 24. DIMYLEUS WOODII, Agass., ... 478
,, 24 *a*. Side view of the same specimen.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIGS. 25, 26. MYLAX BATOIDES, Agass., ... 479
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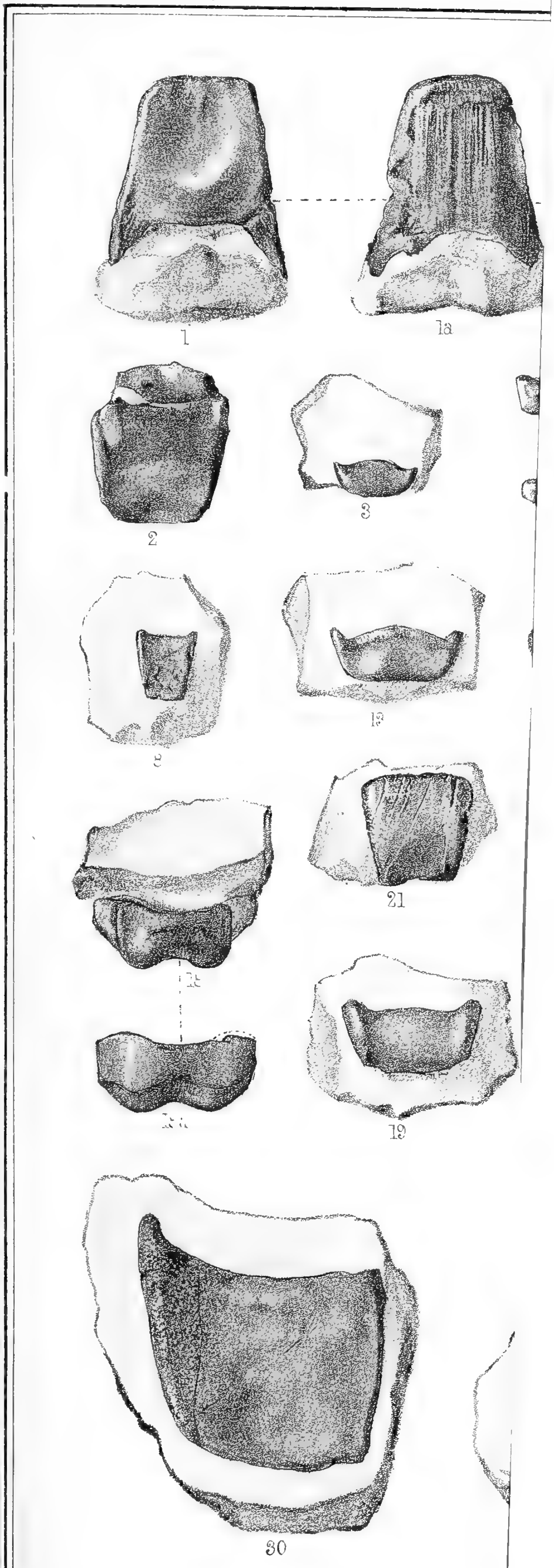
FIGS. 27, 28. MYLACODUS QUADRATUS, Agass., ... 480
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 29. MYLACODUS SESAMINI, Agass., ... 481
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 30. HOMALODUS TRAPEZIFORMIS, Davis, ... 482
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

FIG. 31. HOMALODUS QUADRATUS, Davis, ... 482
Upper surface. Fig. 31 *a*. Under or basal surface.
,, 31 *b*. Lateral surface.
Carboniferous Limestone, Armagh, . . *Ex coll.* Enniskillen Collection.

DESCRIPTION OF PLATE LVIII.



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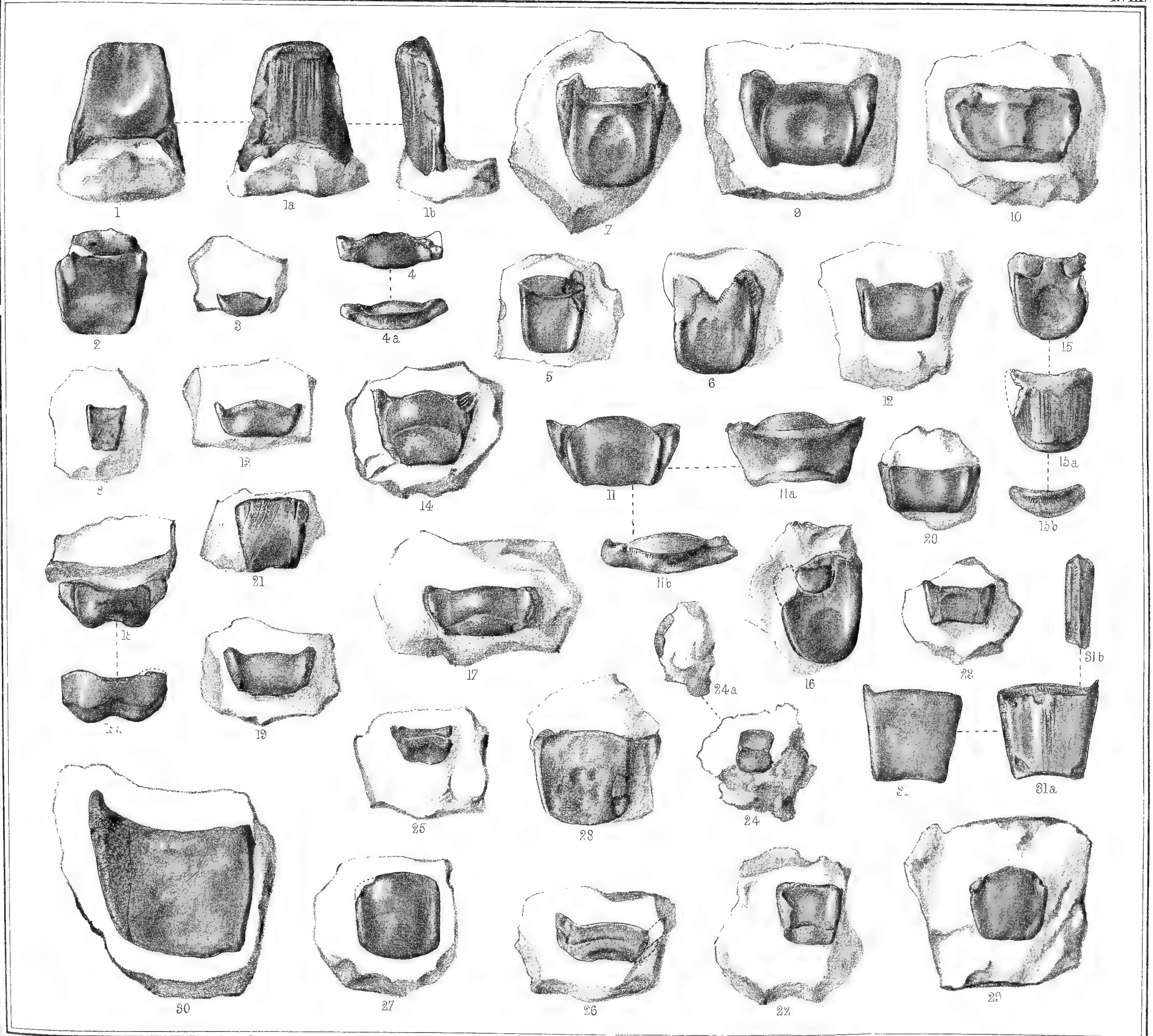

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DESCRIPTION OF PLATE LV.

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FIGS. 1–14. PSEPHODUS MAGNUS, Agass., ... 439

FIGS. 1, 2, 3. A set of three teeth which probably occupied the ramus of one jaw.

FIGS. 1 *a*, 2 *a*, 3 *a*. The same set of teeth, showing under-surface hollowed out for attachment to the jaw.

FIG. 4. Three helodoid teeth of PSEPHODUS MAGNUS in natural position relative to each other.

FIG. 5. Under-surface of larger specimen similar to figure 3.

FIG. 6. Two attached teeth showing crenulated edges.

FIGS. 7, 8, 12. Several teeth of PSEPHODUS MAGNUS.

FIG. 9. Three teeth in natural relative position, attached.

FIG. 10. Side view of tooth, probably from the upper jaw, highly convoluted with crenulated edge.

FIG. 11. Side view of small tooth.

FIGS. 13, 14. Two large posterior teeth, much worn by attrition.
All from Mountain Limestone, Armagh, *Ex coll.* Enniskillen Collection.

FIGS. 15–18. TOMODUS CONVEXUS, Agass., ... 446

FIG. 15 *a*. Transverse section of tooth represented by figure 15.

FIGS. 16, 17. Teeth probably occupying opposite rami of the jaw.

FIG. 16 *a*. Side view of figure 16, showing its enrolled form.
Mountain Limestone, Bristol, *Ex coll.* Fig. 16, Bristol Museum. Figs. 15 and 17, Enniskillen Collection.

FIG. 18. TOMODUS CONVEXUS, Agass.
Smaller elongated teeth.

FIG. 18 *a*. Longitudinal section of same tooth.
Mountain Limestone, Bristol, . . *Ex coll.* Bristol Museum.

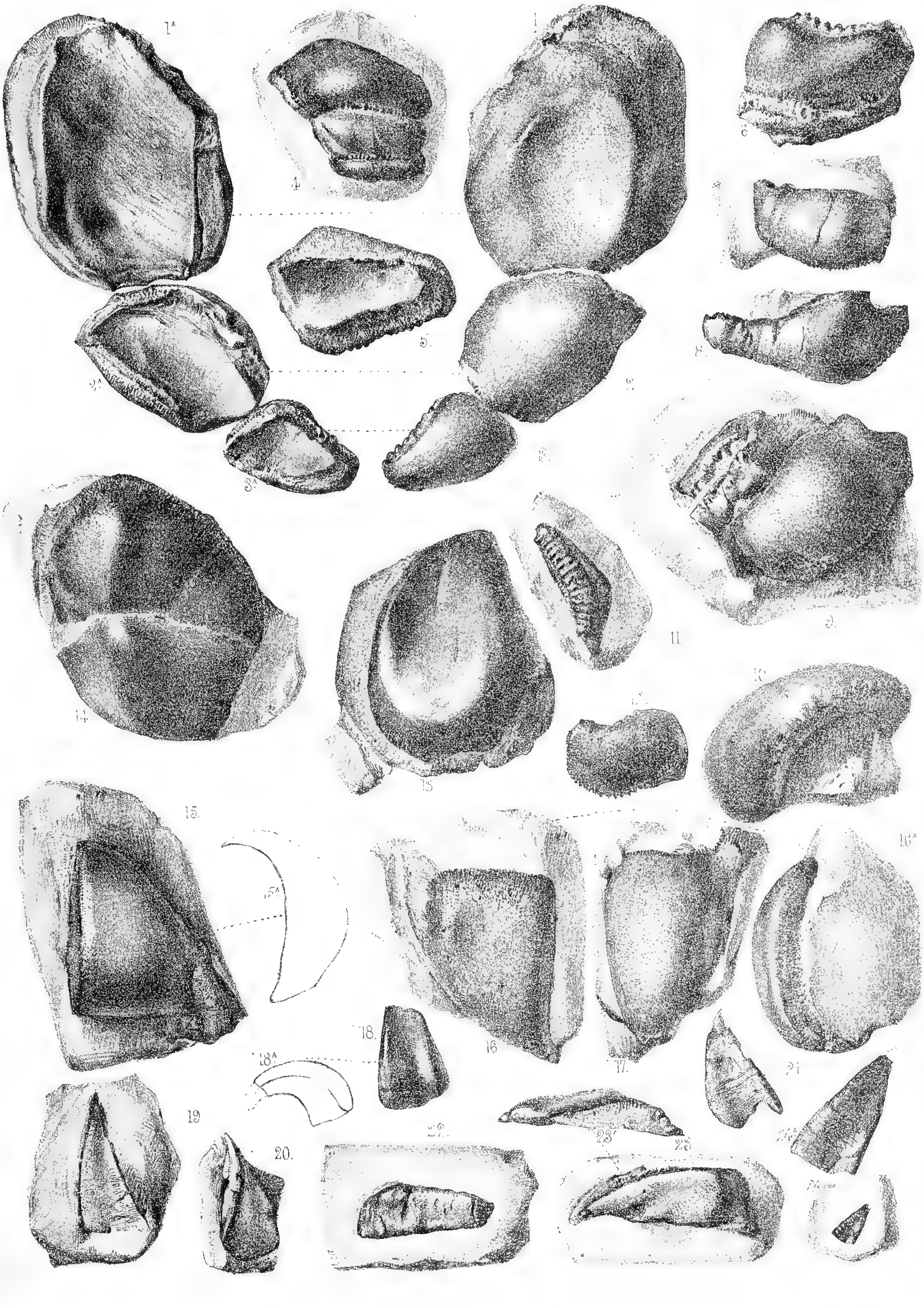
FIGS. 19, 20, 21. XYSTRODUS AUGUSTUS, Agass., ... 449
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 22, 23. XYSTRODUS EGERTONI, Davis, ... 450

FIG. 23 *a*. Lateral aspect of same specimen, figure 23.
Mountain Limestone, Bristol, . *Ex coll.* Enniskillen Collection.

FIG. 24. XYSTRODUS PULCHELLUS, Davis, ... 450

FIG. 24 *a*. The same magnified.
Mt. Limestone, Wensleydale, Yorkshire, *Ex coll.* Reed Collection, York.



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DESCRIPTION OF PLATE LVI.

PLATE LVI.

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FIGS. 1–7. PSAMMODUS RUGOSUS, Agass., ...	459

FIG. 1. Upper surface of a large example of the commonest form of the teeth.

„ 1 *a.* Lateral view of the base of same specimen.

„ 1 *b.* Anterior extremity of the same, showing thickness of base and crown.

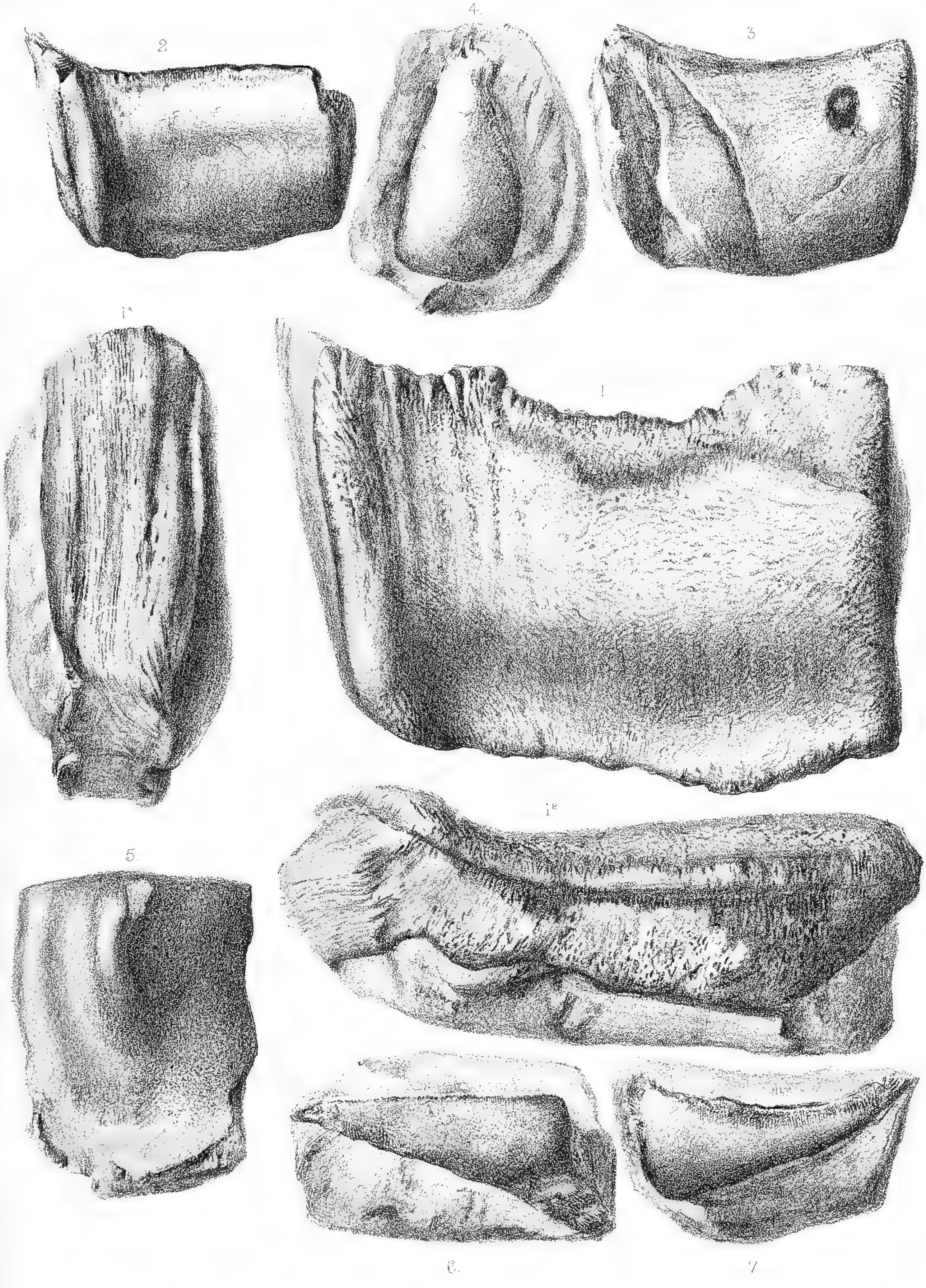
FIGS. 2, 3, 5. Examples of ordinary form of the teeth. The upturned left lateral extremity of figure 2, may be noted. The hollow has probably been produced by the grinding of the opposing teeth. The hump of figure 5, is also peculiar.

FIGS. 4, 6. Triangular teeth occupying the positions indicated in the woodcut on page 462, at the anterior extremity of the palate.

Mountain Limestone, Armagh, . . *Ex coll.* Bristol Museum.

FIG. 7. Triangular tooth, similar to those above.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.



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DESCRIPTION OF PLATE LIX.

PLATE LIX.

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FIGS. 1–2. HELODUS CRASSUS Davis, ...		453
,, 1. Profile of posterior aspect of medium-sized tooth.		
,, 1 *a*. View of the upper surface of crown from above.		
,, 2. Profile of anterior aspect of tooth.		
,, 2 *a*. Lateral elevation of the same tooth.		
Carboniferous Limestone, Armagh, .	*Ex coll.* Enniskillen Collection.	
FIGS. 3, 4. HELODUS TENUIS, Davis, ...		454
,, 3. Posterior aspect of the tooth.		
,, 4. Anterior aspect of tooth imperfect on left extremity.		
,, 4 *a*. Lateral elevation of same tooth.		
Carboniferous Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
FIGS. 5, 6. HELODUS CLAVATUS, Davis, ...		455
,, 5. View of the upper surface of crown from above.		
,, 6. Front view of another tooth.		
,, 6 *a*. Side view of same tooth.		
Carboniferous Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
FIG. 7. HELODUS ACUTUS, Davis, ...		455
,, 7 *a*. Lateral elevation of same specimen.		
Carboniferous Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
FIG. 8. HELODUS RICHMONDIENSIS, Davis, ...		456
Anterior aspect.		
,, 8 *a*. Side view of the same tooth.		
Carb. Limestone, Richmond, Yorkshire,	. *Ex coll.* Enniskillen Collection.	
FIG. 9 HELODUS TRIANGULARIS, Davis, ...		456
Anterior or front view of the tooth.		
,, 9 *a*. Side view of the same tooth.		
,, 9 *b*. Posterior or back view of the same tooth.		
Carboniferous Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
FIG. 10. HELODUS EXPANSUS, Davis, ...		457
,, 10 *a*. Side view of the same specimen.		
Carboniferous Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
FIG. 11. HELODUS RUDIS, M'Coy, ...		457
,, 11 *a*. View of the crown surface from above.		
Carboniferous Limestone,	*Ex coll.* Museum Geological Society, London.	
FIGS. 12–15. PLEURODUS WOODI, Davis, ...		458
Carboniferous Limestone, Richmond, Yorkshire,		
	Ex coll. Wm. Horne, Esq., Leyburn; Reed Collection, York Museum.	
FIGS. 16–21. PETALODUS HASTINGSIÆ, Owen, ...		493
,, 16, 19. Front views of average-sized specimens.		
,, 16 *a*. Longitudinal section of same tooth.		
,, 17. Posterior concave surface of another example.		
,, 18, 20, 21. Distorted specimens, probably from the posterior extremity of the jaw.		
Mountain Limestone, Armagh, .	. *Ex coll.* Enniskillen Collection.	
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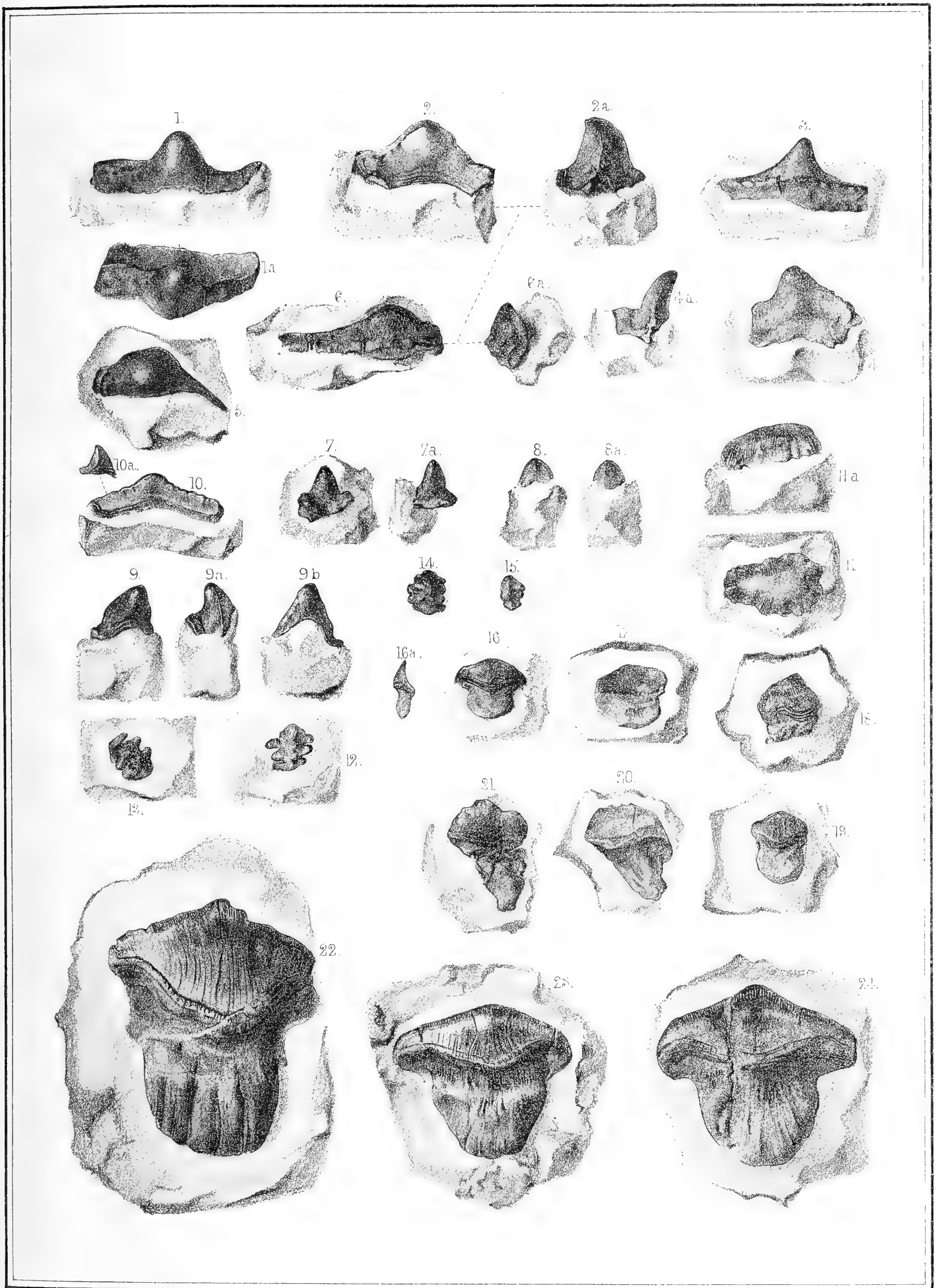
,, 22. Very large specimen—front view—base having the appearance of being divided like Polyrhizodus.		
Carboniferous Limestone, Richmond, Yorkshire,		
	Ex coll. Reed Collection, York Museum.	
FIG. 24. PETALODUS ACUMINATUS, Agass., ...		494
Carboniferous Limestone, Richmond,	. *Ex coll.* Enniskillen Collection.	



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DESCRIPTION OF PLATE LX.

PLATE LX.

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FIG. 1. PETALODUS GRANDIS, Davis, ... 496
Posterior aspect of a large tooth, natural size.
Carboniferous Limestone, Armagh, *Ex coll.* Enniskillen Collection.

FIG. 2. PETALODUS RECURVUS, Davis, ... 497
Mountain Limestone, Bristol, . . *Ex coll.* Enniskillen Collection.

FIGS. 3, 4. PETALODUS INEQUILATERALIS, Davis, ... 497
,, 3. Anterior view of an average-sized specimen.
,, 4. Posterior view of another example.
Mt. Limestone, Wensleydale, Yorkshire, *Ex coll.* Enniskillen Collection.

FIG. 5. PETALODUS RECTUS, Agass., ... 495
Carboniferous Limestone, Lowick.

FIG. 6. PETALOPSODUS TRIPARTITIS, Davis, ... 499
,, 6 *a*. Transverse section of figure 6.
Carb. Limestone, Wensleydale, Yorkshire, *Ex coll.* Wm. Horne, Esq.

FIGS. 7, 8. POLYRHIZODUS RADICANS, Agass., ... 500
,, 7. Anterior surface of a large specimen.
,, 8. Posterior or concave surface of another specimen.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

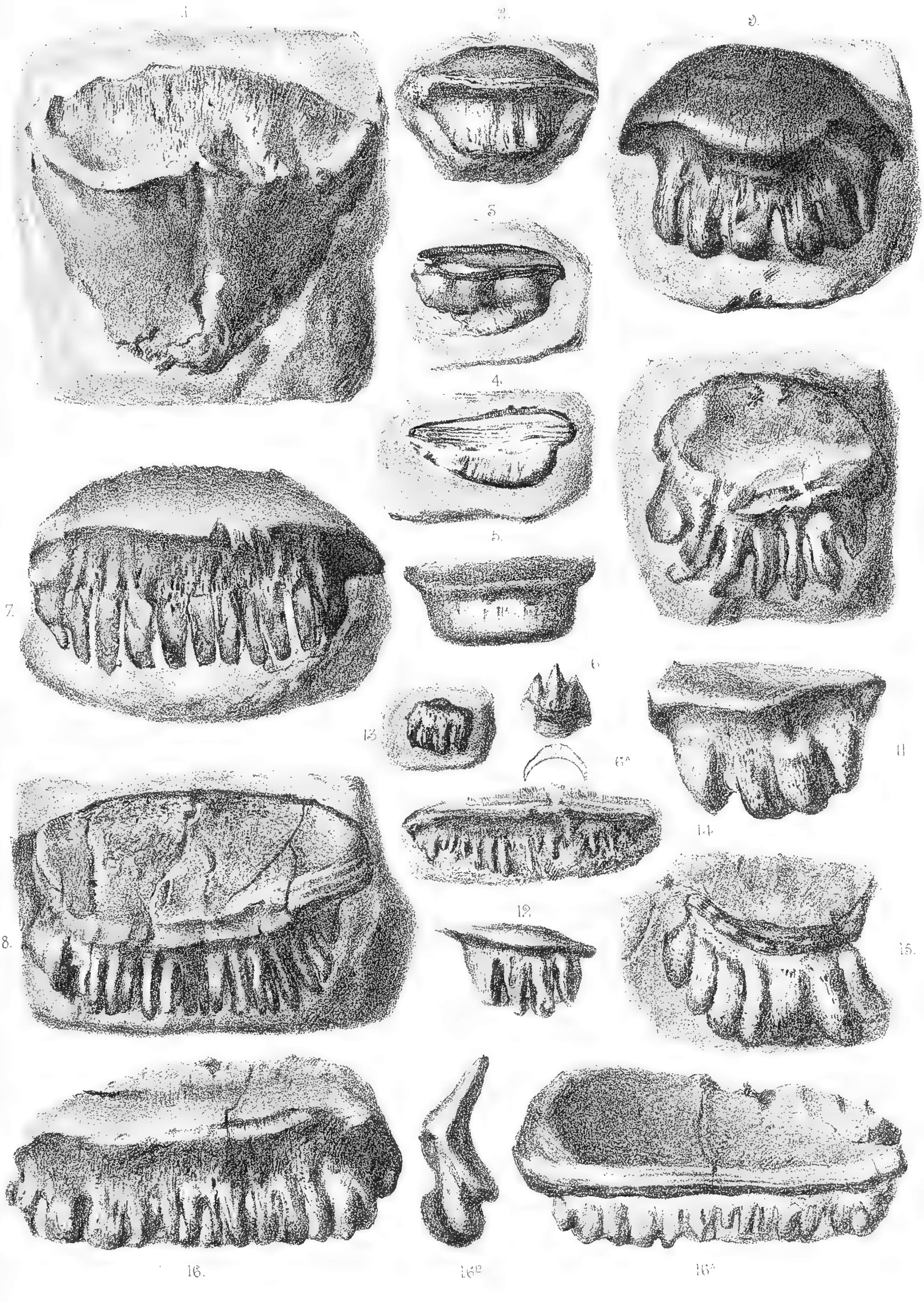
FIGS. 9, 10. POLYRHIZODUS COLEI, Davis. 502
,, 9. Convex front surface of a large specimen.
,, 10. Concave posterior surface of another specimen.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 11, 12, 13. POLYRHIZODUS SINUOSUS, Davis, ... 504
,, 11. Anterior face of a large example.
,, 12. A smaller example with lateral prolongations of the crown surface.
,, 13. Small specimen, probably immature, with crown, small and imperfectly developed.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 14. POLYRHIZODUS ATTENUATUS, Davis, ... 505
Anterior face of medium-sized example.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 15. POLYRHIZODUS CONSTRICTUS, Davis, ... 506
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 16. POLYRHIZODUS ELONGATUS, Davis, ... 503
Convex anterior surface.
,, 16 *a*. Concave posterior surface.
,, 16 *b*. Longitudinal section of tooth.
Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.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6A
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14
12
8.
15.
16.
16B
16A

DESCRIPTION OF PLATE LXI.

PLATE LXI.

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FIG. 1. CHOMATODUS LINEARIS, Agass., ... 508

View of surface of crown from above.

„ 1 *a*. Longitudinal section of same tooth.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 2. CHOMATODUS ACUTUS, Davis, ... 509

Front view of an example imperfect at one end.

„ 2 *a*. Longitudinal section of the same tooth.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 3–5. GLOSSODUS MARGINATUS, M'Coy, ... 510

„ 3. Anterior aspect of an example of ordinary size.

„ 3 *a*. Longitudinal section of the same tooth.

„ 3 *b*. Posterior surface of same.

„ 4. Diagrammatic section, exhibiting the arrangement in the mouth.

„ 5. Example, with a pointed apex.

„ 5 *a*. Side view of the same specimen.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 6–8. CTENOPETALUS SERRATUS, Agass., ... 512

„ 6 *a*. Longitudinal section of tooth represented by figure 6.

„ 8. Posterior concave face of another specimen.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 9. CTENOPETALUS CRENATUS, Davis, ... 513

„ 9 *a*. Longitudinal section of same tooth.

„ 9 *b*. Posterior surface of figure 9.

Mt. Limestone, Wensleydale, Yorkshire. *Ex coll.* Wm. Horne, Esq.

FIG. 10. HARPACODUS DENTATUS, Agass., ... 514

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIG. 11. HARPACODUS CLAVATUS, Davis, ... 515

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 12–16. PETALORHYNCHUS PSITTACINUS, Agass., ... 516

„ 12. Anterior surface of a broad and short example.

„ 13. Anterior surface of a much narrower and longer example.

„ 14. View of posterior spatulate surface of a large tooth.

„ 15. Three teeth in natural relative position, horizontally.

„ 16. Five teeth in natural relative position, vertically.

„ 16 *a*. Diagrammatic section through the same, showing how successive teeth become anchylosed to those older and smaller.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

FIGS. 17–22. PRISTODUS FALCATUS, Agass., ... 519

„ 17. View of the interior surface of the upper jaw.

„ 19. View of the exterior surface of the upper jaw, with the pointed apex of the lower one projecting in the interior.

„ 22. Lateral view of the right side of the upper jaw.

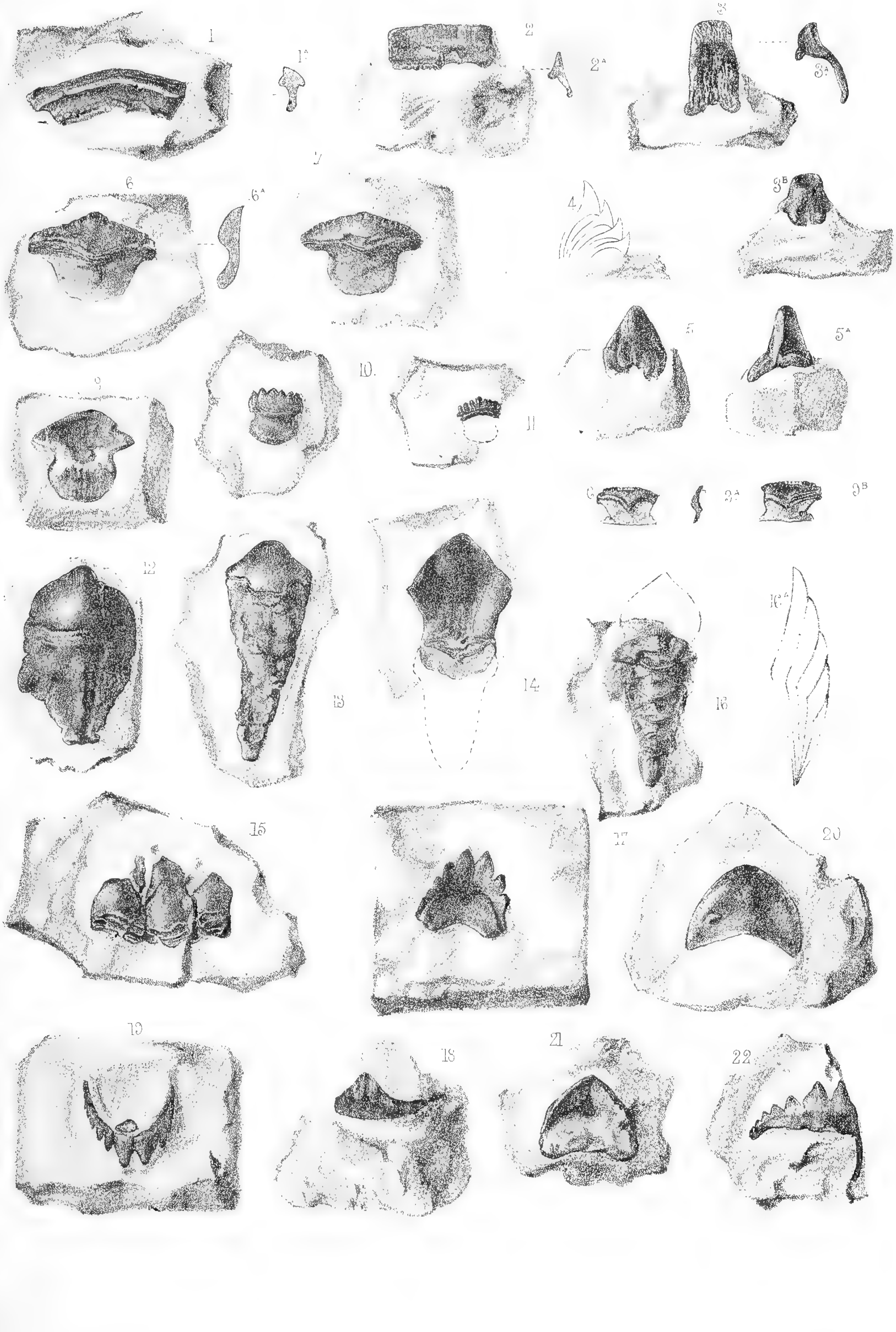
„ 21. View of the interior surface of the lower jaw.

„ 18. View of the exterior surface of the lower jaw.

„ 20. View of the under surface of the lower jaw.

Mountain Limestone, Wensleydale and Richmond, Yorkshire.

Ex coll. Wm. Horne, Esq., and Reed Collection, York Museum.



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DESCRIPTION OF PLATE LXII.

PLATE LXII.

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FIGS. 1–15. ORACANTHUS MILLERI, Agass, ... 525

„ 1. Central dorsal bone of cranium.

„ 2. Upper portion of similar plate represented by figure 1.

, 3. Jugular plate? or sphenoid bone.

„ 4. Upper jaw?

„ 5. Head bone.

„ 6. Cheek plate or operculum?

„ 7. Lower jaw.

„ 8, 10, 11. Bones forming part of the dermal covering of the head.

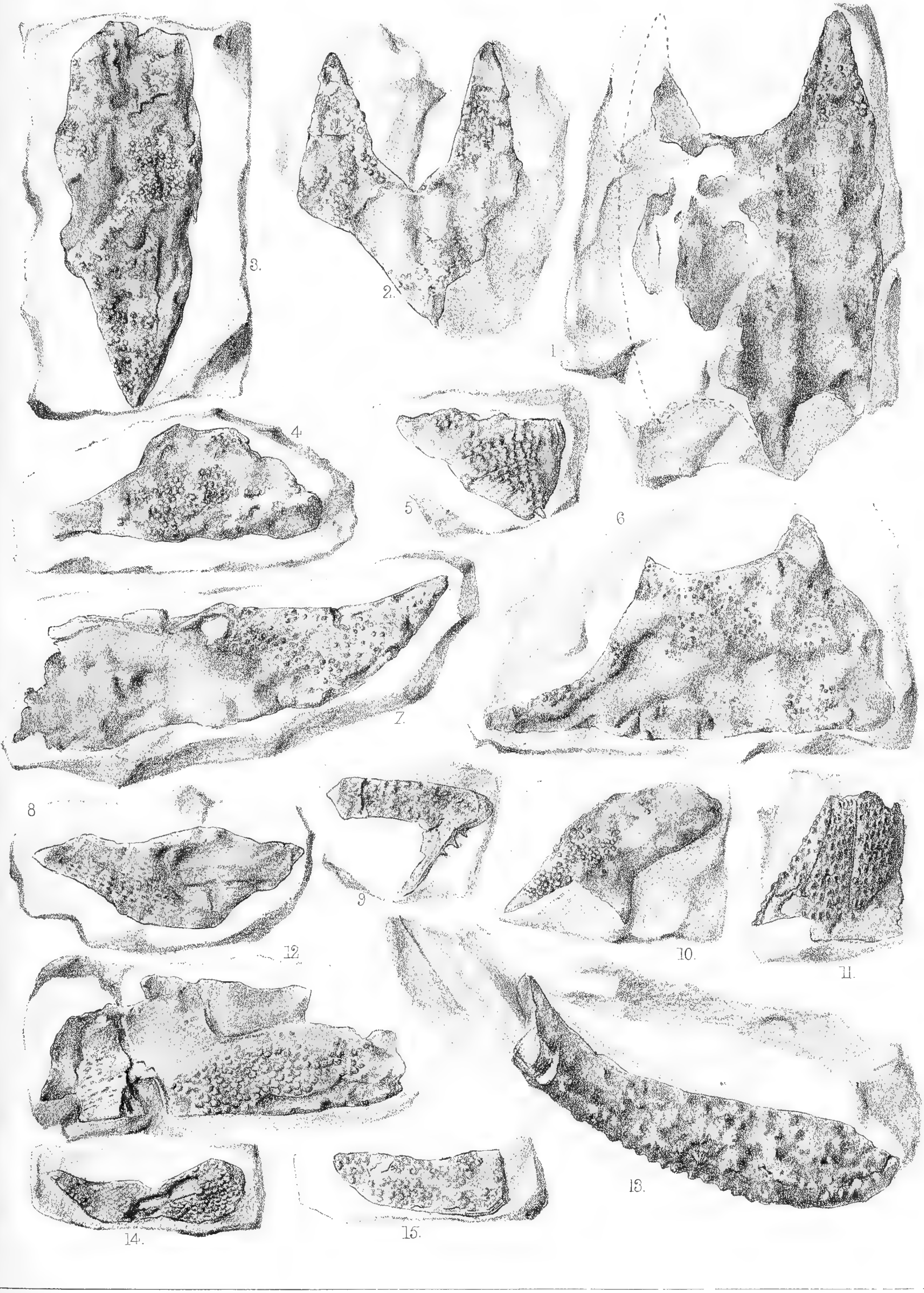
„ 9. Head bone of Oracanthus (Platycanthus isosceles of M'Coy).

, 12. Jugular plate?

„ 13. A peculiar squarely formed bone.

„ 14, 15. Small head bones. (Coccosteus and Asterolepis of M'Coy.)

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.



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DESCRIPTION OF PLATE LXIII.

PLATE LXIII.

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FIGS. 1–4. ORACANTHUS MILLERI, Agass., ... 525

„ 1. Upper or anterior surface of dermal plate.

„ 1 *a*. Lateral view of same specimen.

„ 1 *b*. Section near the apical extremity, showing the thickness of the bony part and large internal cavity.

„ 2. Sinistral example of specimen similar to figure 1.

„ 3. Dextral example of a similar specimen.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.

„ 4. Peculiarly shaped bone, forming some portion of the external covering of the fish.

Mountain Limestone, Bristol, . *Ex coll.* Enniskillen Collection.

FIG. 5. CHEIRODUS PES-RANÆ, M'Coy, ... 523

„ 5 *a*. A magnified view of the same specimen.

Mountain Limestone, Derbyshire, *Ex coll.* Woodwardian Museum, Cambridge.

FIG. 6. COLONODUS LONGIDEUS, M'Coy, ... 523

Mountain Limestone, Armagh, *Ex coll.* Museum of Geol. Society, London.

FIGS. 7–12. External covering of CŒLACANTHUS, Agass., ... 524

FIG. 7. Under-surface of the operculum.

„ 8. Upper-surface of the operculum.

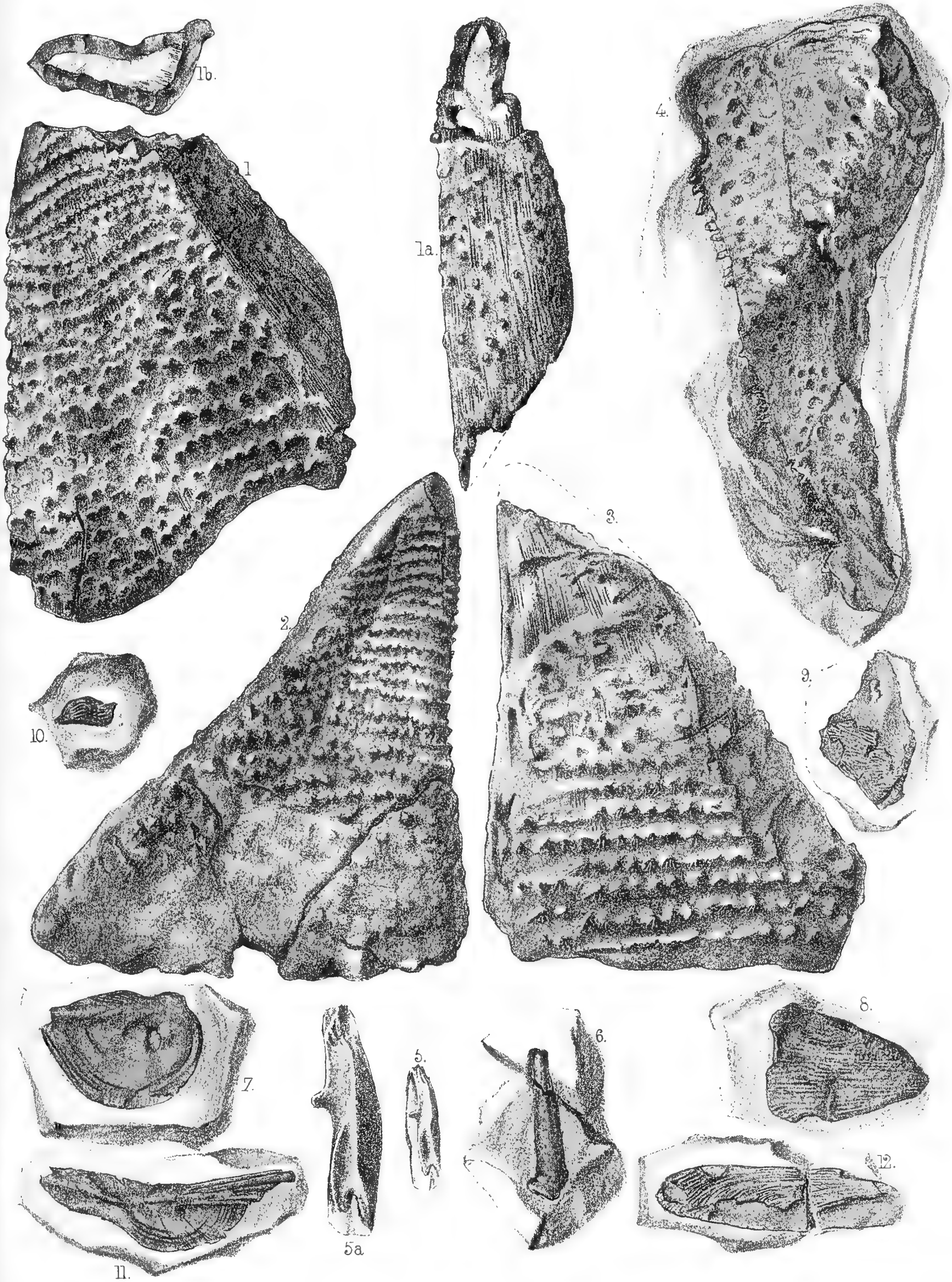
„ 9. Dermal covering from head.

„ 10. Jugular plate.

„ 11. Head plate.

„ 12. Scale.

Mountain Limestone, Armagh, . *Ex coll.* Enniskillen Collection.



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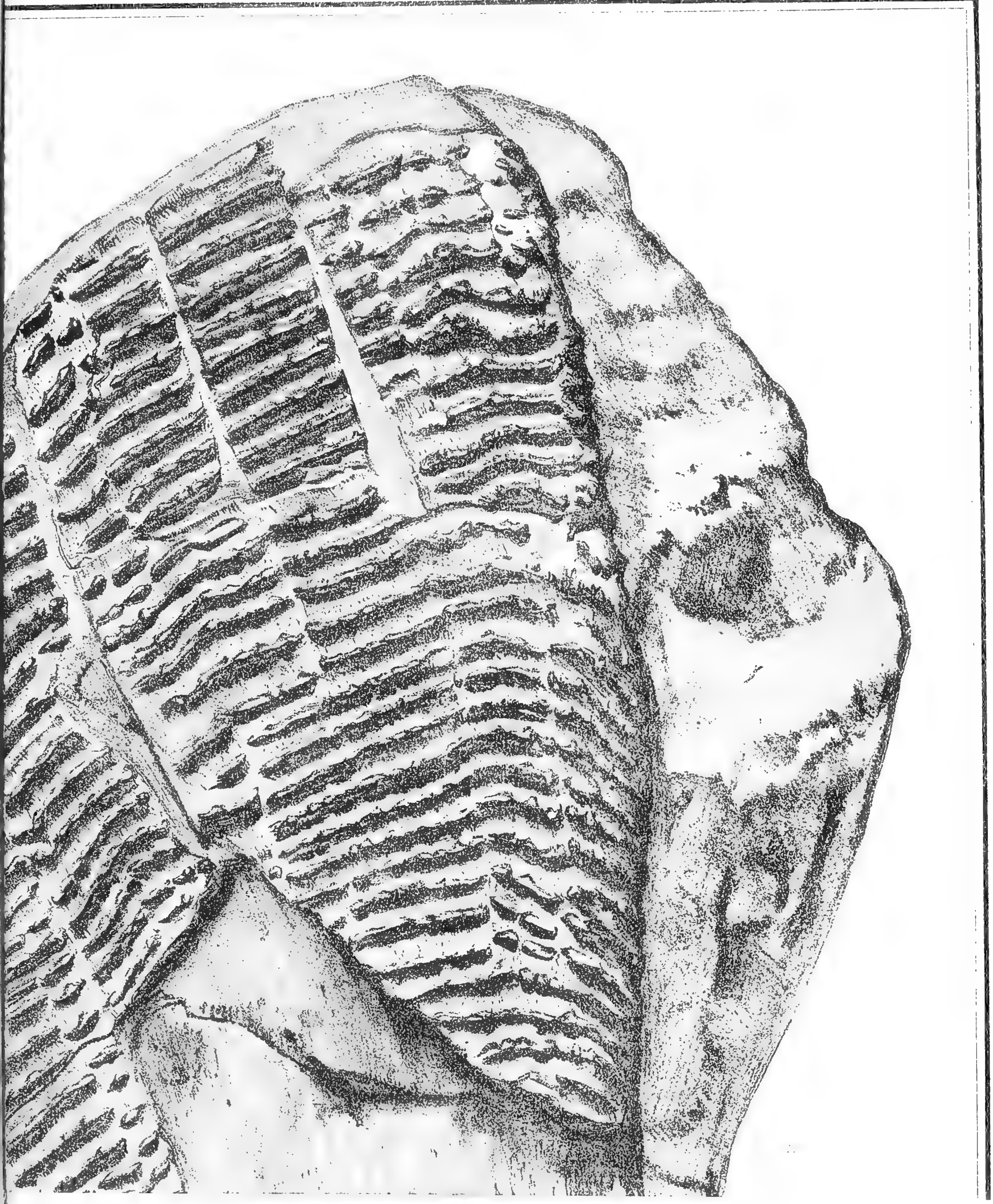
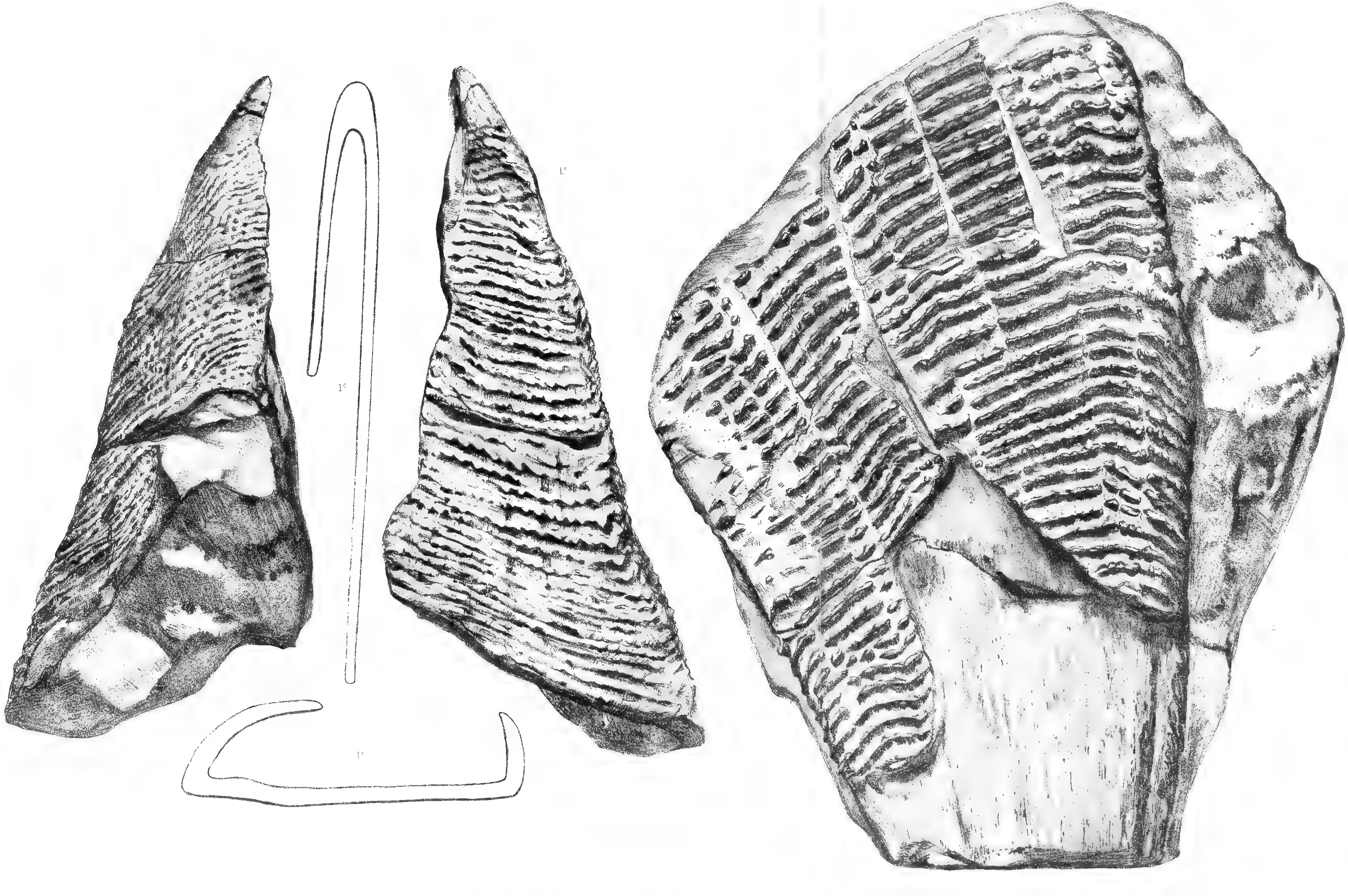
DESCRIPTION OF PLATE LXIV.

PLATE LXIV.

		Page
FIG. 1.	ORACANTHUS MILLERI, Agass., ...	525
	Posterior view of bony dermal covering, with wide and open basal cavity.	
„	1 *a.* Anterior aspect of the same specimen.	
„	1 *b.* Transverse section of the same.	
„	1 *c.* Longitudinal section of the same specimen.	
	Mountain Limestone, Bristol, . *Ex coll.* Enniskillen Collection.	
FIG. 2.	ORACANTHUS MILLERI, Agass., ...	525
	Very large specimen ; imperfect, very thin, and flattened.	
	Mountain Limestone, locality not known.	
	Ex coll. Museum of the Geological Society, London.	





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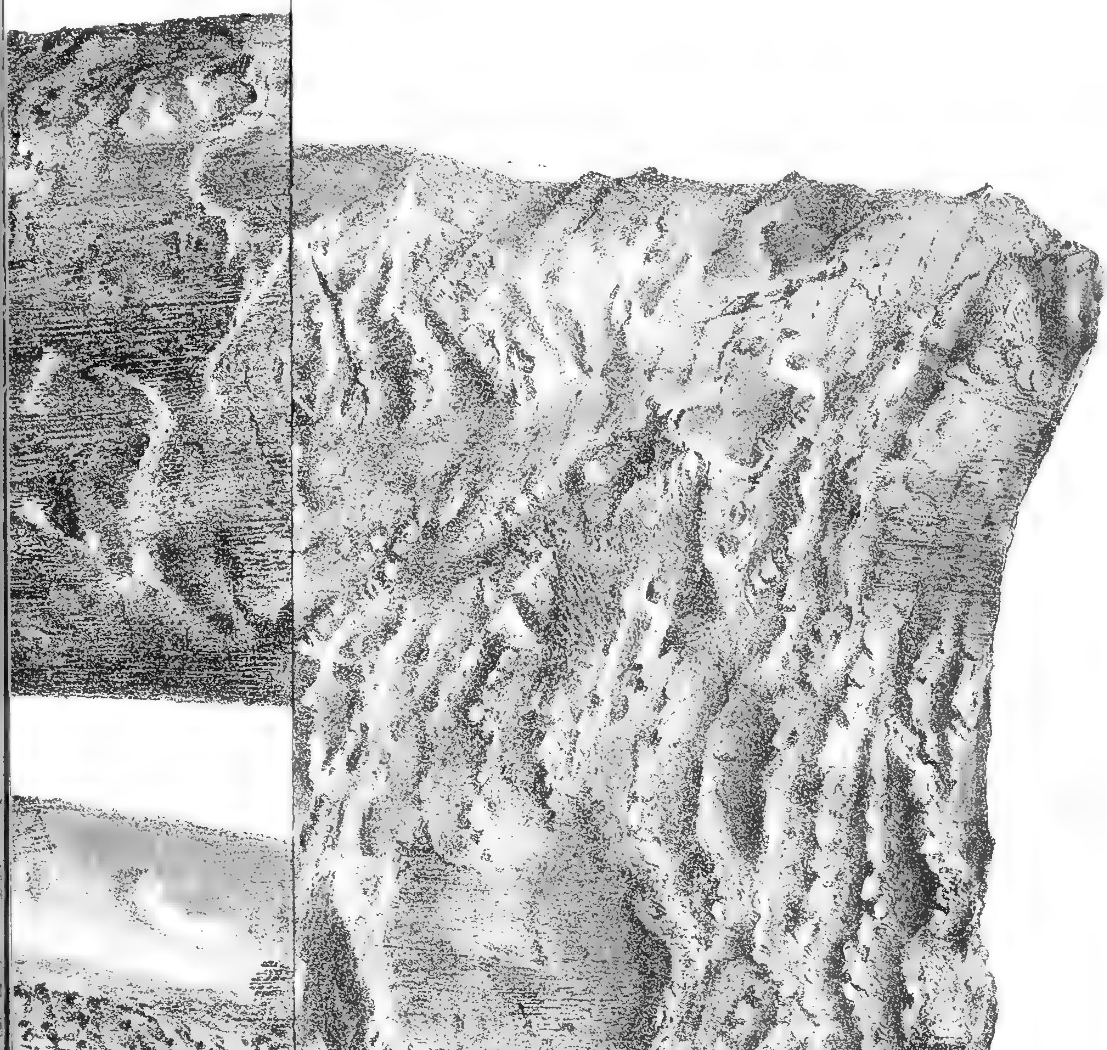
DESCRIPTION OF PLATE LXV.

PLATE LXV.

		Page
FIG. 1. PHODERACANTHUS GRANDIS, Davis, ...		534
,, 1 *a.* Section of the spine near the apical extremity.		
Mt. Limestone, Bristol, .	*Ex coll.* Earl of Ducie, Tortworth Court.	
FIG. 2. STICHACANTHUS TORTWORTHENSIS, Davis, ...		532
,, 2 *a.* Section of the spine near the apical extremity.		
Mt. Limestone, Tortworth, .	*Ex coll.* Earl of Ducie, Tortworth Court.	
FIGS. 3, 4. ORACANTHUS MILLERI, Agass., ...		525
Two peculiar bones apparently pertaining to Oracanthus.		
,, 3. External surface with similar ornament to the dermal coverings of Oracanthus.		
,, 3 *a.* Section of spatulate portion of the same.		
,, 4. Internal aspect of another specimen.		
,, 4 *a.* Section of the same.		
Mountain Limestone, Armagh, .	*Ex coll.* Enniskillen Collection.	



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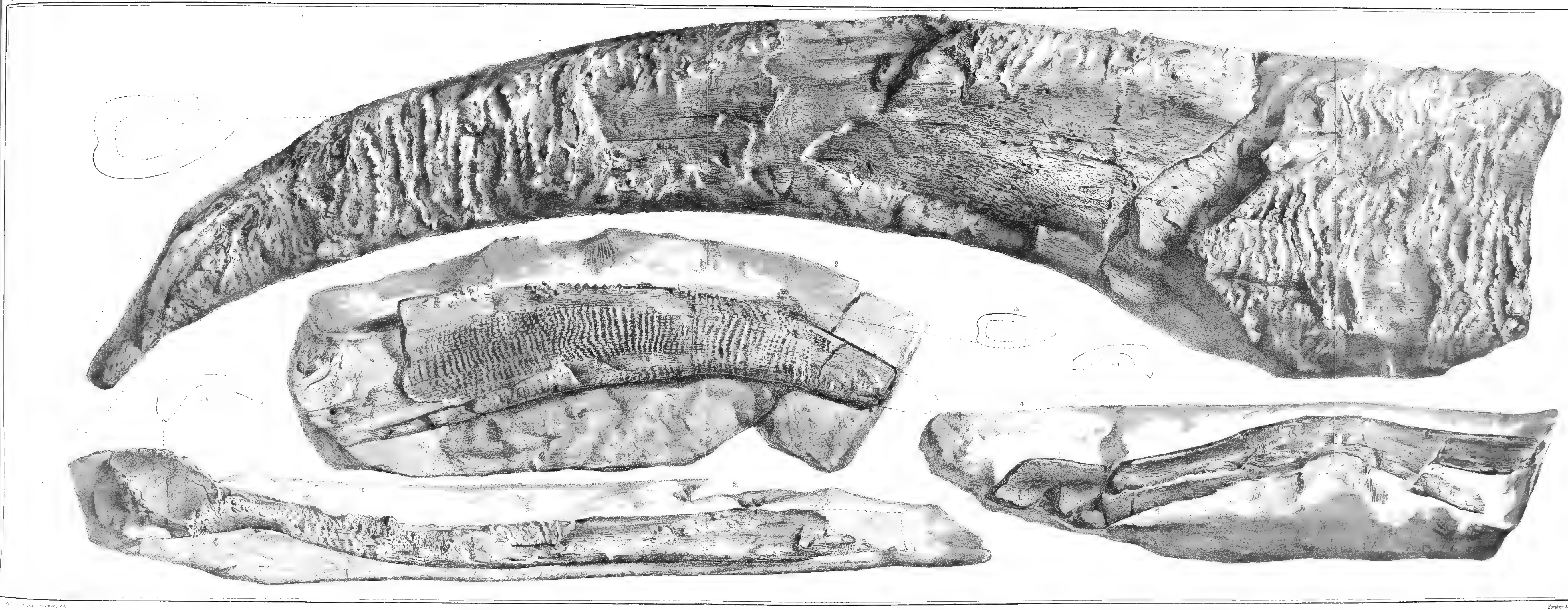

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6. INDEX TO GENERA AND SPECIES.

*** The genera described in the Memoir are printed in CAPITALS, the species in Roman, others and the synonyms in *Italic*.